Appendix B: Emissions Modeling

Introduction

This appendix provides additional details of the methodologies used to estimate control and no-control scenario emissions and the results obtained by these methods. Methodological information and results are provided for each of the six principal emission sectors: industrial combustion, industrial processes, electric utilities, on-highway vehicles, off-highway vehicles, and commercial/residential sources.

The initial section of this appendix assesses the emissions projections presented in this analysis by (1) comparing the 1970 to 1990 control scenario projections with recent EPA *Trends* report estimates for the same years and (2) comparing the 1970 to 1990 trend in no-control scenario projections with 1950 to 1970 emissions as reported in *Trends*. The first comparison indicates that control scenario emissions projections approximate, but do not precisely match, the EPA *Trends* data. The reason for this mismatch is discussed below. The second comparison is useful for demonstrating that pre-1970 emissions trends would not provide a satisfactory basis for extrapolating emissions trends into the 1970 to 1990 period. The inability to simply extrapolate pre-1970 trends provides further justification for applying the present modeling methodologies to generate no-control scenario emissions projections.

The remainder of the appendix provides further details of the emissions modeling conducted in support of the present analysis, and is largely adapted from the draft report "The Impact of the Clean Air Act on 1970 to 1990 Emissions; section 812 retrospective analysis," March 1, 1995 by Pechan Associates. The draft Pechan report surveys the methodologies and results associated with the sector-specific emission modeling efforts by Argonne National Laboratory (ANL), ICF Resources Incorporated (ICF), Abt Associates (Abt), and the Environmental Law Institute (ELI).

Comparison of Emissions Projections with Other EPA Data

Control Scenario Projections Versus EPA Trends Projections

The control scenario emission results are similar, but not identical, to official EPA historical emission estimates provided by the EPA National Air Pollutant Emission Trends Reports.[1] Comparisons between the current estimates and the *Trends* data for SO_2, NO_x, VOC, CO, and TSP are presented in Figures B-1, B-2, B-3, B-4, and B-5 respectively. More detailed tables providing emission estimates by sector and by target year for TSP, SO_2, NO_x, VOC, CO, and Lead are presented in Tables B-16, B-17, B-18, B-19, B-20, and B-21, respectively, at the end of this appendix.

Though the EPA *Trends* and the present study emission profiles are similar to each other, they should not be expected to match precisely. This is because the emission estimates developed for the present study are based on modeled macroeconomic and emission sector conditions. Even though the macroeconomic and sector models themselves are constructed and calibrated using historical data, modeled replications of historical trends would not be expected to precisely capture actual historical events and conditions which affect emissions. Relying on modeled historical scenarios is considered reasonable for the present analysis since its purpose is to estimate the differences between conditions with and without the CAA. Comparing actual historical emissions with modeled no-control emissions would lead to an inconsistent basis for comparisons between scenarios. Using models for both scenarios allows potential model biases to essentially cancel out.

In general, however, these comparisons show close correspondence between control scenario and *Trends* estimates with the largest differences occur-

[1] EPA/OAQPS, "National Air Pollutant Emission Trends 1900 - 1994," EPA-454/R-95-011, October 1995.

Figure B-1. Comparison of Control, No-control, and *Trends* SO_2 Emission Estimates.

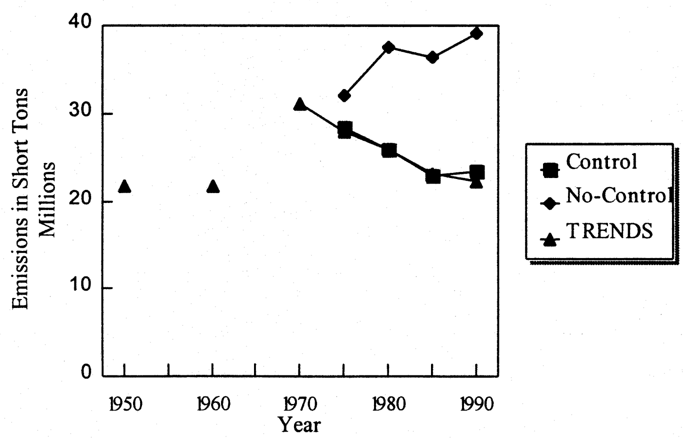


Figure B-2. Comparison of Control, No-control, and *Trends* NO_x Emission Estimates.

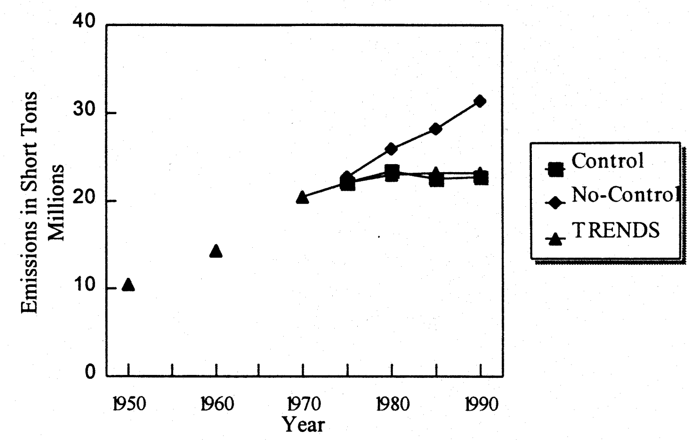


Figure B-3. Comparison of Control, No-control, and *Trends* VOC Emission Estimates.

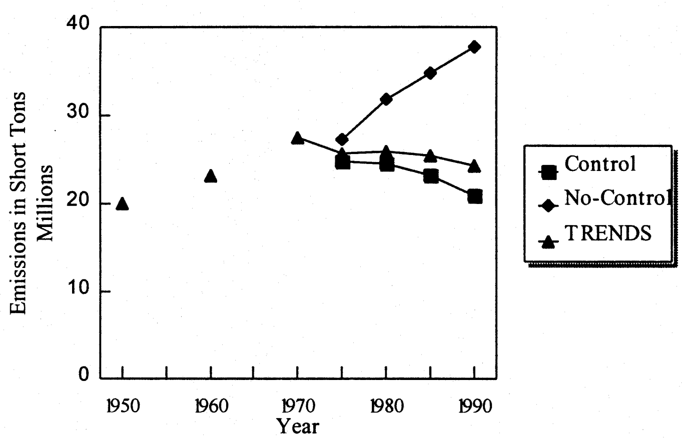


Figure B-4. Comparison of Control, No-control, and *Trends* CO Emission Estimates.

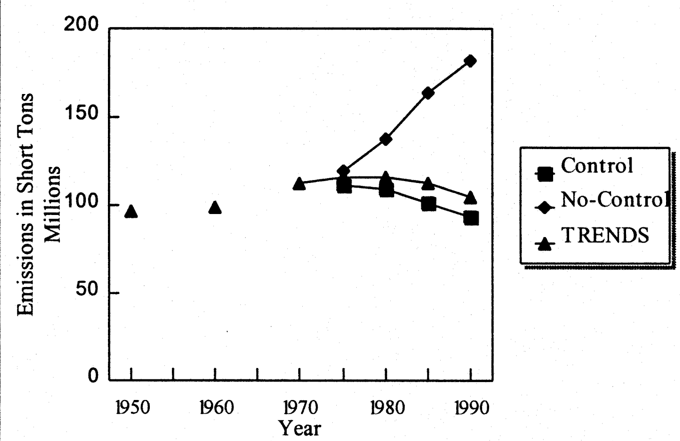
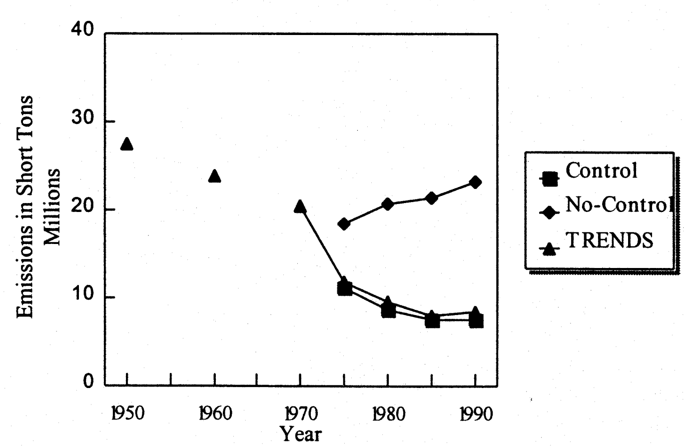


Figure B-5. Comparison of Control, No-control, and *Trends* TSP Emission Estimates.



ring for VOC and CO emissions. The *Trends* report VOC estimates are generally higher than the control scenario estimates due to the inclusion of Waste Disposal and Recycling as a VOC source in the *Trends* report. This inconsistency is of no consequence since Waste Disposal and Recycling sources were essentially uncontrolled by the historical CAA and therefore do not appear as a difference between the control and no-control scenarios. The higher CO emission estimates in the *Trends* Report are primarily associated with higher off-highway vehicle emissions estimates. Again, since off-highway emissions do not change between the control and no-control scenario in the present analysis, this inconsistency is of no consequence.

No-Control Scenario Projections Versus Historical EPA Trends Data

Comparisons between the control scenario emissions estimates generated for the present study and 1970 to 1990 emissions estimates obtained from the *Trends* Report are useful for assessing the reasonableness of the control scenario estimates. As indicated above, there is close correspondence between the control scenario and the *Trends* Report. It may also be useful to compare the pre-1970 historical emissions data from the *Trends* Report[2] with the no-control scenario estimates presented herein to assess whether these pre-1970 trends can be reasonably extrapolated to the 1970 to 1990 period. In addition, examination of any significant changes in emissions trends between the pre-1970 *Trends* data and post-1970 no-control projections might indicate flaws in the emissions modeling conducted for the present study.

For SO_2, the 1950 to 1970 *Trends* data in Figure B-1 demonstrate the effects of the huge increase in fossil fuel combustion between 1960 and 1970. This net increase occurred, despite the obsolescence of coal-fired locomotives and reductions in coal refuse burning, largely because utility emissions nearly doubled between 1950 and 1960, and nearly doubled again between 1960 and 1970.[3] Although no-control scenario projections for the post-1970 period show significant additional increases in SO_2 emissions, the rate of growth is markedly slower than during the 1950 to 1970 period.

The *Trends* data for 1950 to 1970 NO_x shown in Figure B-2 indicate the steady increase in emissions resulting from increased combustion of natural gas and gasoline.[4] The post-1970 emissions estimates derived for the present study reflect a continuation of this trend.

Emissions of VOCs increased steadily over the 1950 to 1970 period, as shown in Figure B-3, primarily due to increases in industrial production and vehicular travel.[5] The no-control scenario emission estimates continue this trend throughout the 1970 to 1990 period, with some acceleration of the rate of change due to the rapid increase in VMT projected under this scenario.

The *Trends* data shown in Figure B-4 for CO indicate an overall increase between 1950 and 1970. This increase occurred despite significant reductions in emissions from stationary source fuel combustion and industrial processes because mobile source emissions nearly doubled during this period.[6] Under the no-control scenario of the present study, additional reductions from stationary sources are not available to offset the transportation-related increases; therefore, the rate of increase in CO emissions after 1970 under the no-control scenario reflects the rapid increase in mobile source emissions caused by increases in vehicle miles traveled.

Finally, Figure B-5 demonstrates a directional shift in emissions of primary particulates between the 1950 to 1970 *Trends* data and the post-1970 no-control scenario. The declining trend from 1950 to 1970 indicated by the *Trends* data, however, is largely due to reductions in use of coal-fired locomotives, reductions in residential coal-burning, coarse (i.e., visible) particle emissions controls installed on fossil fuel combustors and industrial processes, and reductions in forest fires and other open burning.[7] Since the reductions achievable from these sources were largely

[2] While 1970 to 1990 Trends data were obtained from more recent *Trends* reports, the 1950 to 1970 *data* were obtained from the November 1991 report since this was the last year the *Trends* report series included data for this period.

[3] U.S. EPA, “National Air Pollutant Emission Estimates, 1940 - 1990”, EPA-450/4-91-026, November 1991, Table 4, p. 16.

[4] U.S. EPA, “National Air Pollutant Emission Estimates, 1940 - 1990”, EPA-450/4-91-026, November 1991, p. 42.

[5] U.S. EPA, “National Air Pollutant Emission Estimates, 1940 - 1990”, EPA-450/4-91-026, November 1991, p. 42.

[6] U.S. EPA, “National Air Pollutant Emission Estimates, 1940 - 1990”, EPA-450/4-91-026, November 1991, Table 7, p. 19.

[7] U.S. EPA, “National Air Pollutant Emission Estimates, 1940 - 1990”, EPA-450/4-91-026, November 1991, Table 3, p. 15.

achieved by 1970, they are no longer available to offset the increases observed from other source categories (e.g., highway vehicles). The no-control scenario therefore shows a steady increase in overall emissions of primary particulates after 1975.

The following sections of this appendix summarize the methodologies used to model control and no-control scenario emissions for each of the six major emission sectors. Additional details can be found in the supporting documents listed in the References section of this appendix.

Industrial Boilers and Processes

For the purposes of the retrospective analysis, the industrial sector was divided into two components: (1) boilers; and (2) industrial processes and process heaters. The factors affecting emissions from these two source types are different, and, as a result, separate methods were used to calculate control and no-control scenario emissions in each of the target years. To analyze the change in emissions from industrial boilers, ANL used the ICE model (Hogan, 1988). This model was developed under the auspices of NAPAP to forecast State-level fuel choice and emissions from conventional, steam raising, industrial boilers. For the retrospective analysis of industrial processes and fuel use emissions from process heaters, ELI used the EPA *Trends* methods and the ANL MSCET data base (EPA, 1991; Kohout et al., 1990). The *Trends* report contains estimates of national emissions for a variety of industrial sources for the time period of interest. The MSCET data base provided the spatial distribution used to calculate State-level emissions.

The distinction between industrial boilers and non-boiler industrial processes was necessitated by the structure of the CAA regulations and by the factors affecting emission levels from these two source types. Boilers are regulated differently from processes and process heaters. Emissions from industrial processes are primarily a function of levels of industrial activity. The emissions from fuel combustion, however, are a function of energy use and fuel choice as well as industrial activity. Fossil fuel emissions in the absence of the CAA are not proportional to industrial output, since the level of energy use is a decision variable for the firm in its production process. Therefore, in the ICE model simulations used to estimate no-control scenario boiler emissions, the level (and type) of energy use were determined first, and then the effects of emission regulation were taken into account.

Overview of Approach

Industrial Boilers

ICE model inputs include fuel prices, total boiler fossil fuel demand by industry type, and environmental control costs. The outputs of the ICE model were SO_2, NO_x, and TSP emissions by State, industry, and boiler size class. The model runs in 5-year increments and has a current base year of 1985.

The model required boiler demand input data at the State level. Seven industry types were included in the ICE model: Standard Industrial Classification (SIC) codes 20, 22, 26, 28, 29, 33, and "other manufacturing." ANL's approach assumed that industrial boiler fuel use occurs only in the manufacturing sector. The model also required fuel price data in each of the target years at the Federal Region level. Prices by grade of coal and petroleum product, such as sulfur content and heating value, were used by the model to determine the cost of compliance, and to determine emissions when the regulations are not binding.

Control costs were computed by engineering subroutines in the model. These costs were used by the ICE model's fuel choice component to determine the effect of CAA-related costs on the market share of a particular fuel. This fuel choice decision only applies to new industrial boilers, since the cost of existing emission controls are not in the ICE data base and fuel choice is not re-evaluated for existing boilers.

Industrial Processes and In-Process Fuel Combustion

The calculation of historical emissions from industrial processes uses EPA *Trends* methods to estimate national emissions for the analysis years, then allocates these emissions to States using the State shares from the MSCET data base.

MSCET uses a variety of methods to estimate historical emissions for the various industrial sectors. For industrial process emissions, MSCET is based on historical data on industrial activity to allocate emissions based on the State level distribution of the polluting activities. The State level distribution and benchmark is based on the 1985 NAPAP Inventory (EPA, 1989). This approach implies that the MSCET data corresponds directly to the 1985 NAPAP Inventory, and that, for any State, the sum of the emissions from Source Classification Codes (SCCs) that comprise the MSCET industry sector are equal to the MSCET data for that State and sector. Data from *Trends* are used by MSCET to provide information on changes in the aggregate level of control for years other than the 1985 benchmark. Since no direct correspondence existed between the *Trends* data and MSCET, a relationship was developed to link MSCET sectors to *Trends* industry categories and to industry categories in the J/W model, which was used to change activity levels for the no-control scenario.

Table B-1 shows the relationship between the sector definition used by MSCET, *Trends*, and the J/W model. The mapping from MSCET to J/W and *Trends* is used to provide the changes in aggregate activity and emission control for the calculation of no-control scenario emissions.

Establishment of Control Scenario Emissions

Energy use and corresponding emissions were broken down between boilers and non-boiler industrial processes. The latter category includes furnaces, kilns, internal combustion engines (e.g., compressors), and other non-steam types of process heat. The focus of this analysis is on boiler emissions, which were subject to increasingly stringent regulations over the 1970 to 1990 period. (Emissions from some types of industrial processes were also regulated, but regulation of non-boiler sources was targeted on the emissions from the industrial process itself, not on its fuel combustion) For this study, ANL assumed that only boiler fuel use is affected by emission regulations. The non-steam boiler portion of industrial fuel use is not directly affected by the CAA. This portion of the emissions may be affected indirectly by changes in industry activity level and fuel consumption. The emissions from non-boiler industrial processes were calculated separately by ELI.

Control Scenario Boiler Emissions

Control scenario boiler SO_2, NO_x, and TSP emissions were calculated by the ICE model. The MSCET data base provided an estimate of historical emissions for total fossil fuel combustion by industry. Since MSCET does not identify the two required components of boiler and non-boiler emissions, ANL defined the residual of the ICE model control scenario and MSCET as the non-boiler or in-process fuel use emissions. For the relevant study period, MSCET provided a control scenario estimate of total boiler and non-boiler emissions, which was used to calculate the control scenario State-level boiler emissions based on a special run of the ICE model.[8]

In order to use ICE to model the historical emissions path, it was necessary to construct a new ICE model base year file and new user input file so that the model could begin its calculations from 1975 conditions. Construction of the base year file was completed in two stages, using two different data sources, as discussed below. The user input file has several elements, including energy prices and historical boiler fuel use; its construction is discussed in the next section. The model base year file provided the energy use in boilers and corresponding emission control regulations (State Implementation Plans –SIPs– for example) by several categories. These categories include:

- State;
- Industry group (one of seven);
- Fuel type (natural gas, distillate or residual fuel oil, and coal);
- Boiler size class (MMBTU/hr, one of eight categories);
- Utilization rate (one of five categories); and
- Air quality control region (AQCR).

For the purposes of ANL's analysis, only the first three categories were assumed to vary. In other words, for each State, industry, and fuel type combination, the distribution of boiler size, utilization rate, and AQCR was assumed to be constant. Over time, however, changes in the aggregate composition of State, industry, and fuel type would cause corresponding changes in the aggregate composition of the other three characteristics. As mentioned previously, the current base year file was 1985. The retrospective analysis required a 1975 base year. Because of data limitations, the approach to construct a new base year was achieved in the following two steps: the construction of a 1980 interim base year file from the 1985 file, and then the construction of the 1975 file from the interim 1980 file.

[8] MSCET does not provide State-level estimates of TSP, while ICE does. To estimate total regional TSP from fuel combustion, the *Trends* model was employed. These national emissions estimates were allocated to the States based on the State-level shares of TSP from the NAPAP inventory.

Table B-1. Correspondence Between Process Emissions Categories Used by MSCET, *Trends*, and J/W Industrial Sectors and Identifier Codes.

MSCET Category	MSCET Code	*Trends* Industry Category	J/W Code	J/W Industry Category
Food Proc. and Agric. Operations	FOODAG	Cattle Feed Lots (0211)	1	Agriculture/forestry/fisheries
		Cotton Ginning (0724)		
		Feed and Grain Milling (204)		
		Grain Elevators (4421,5153)		
Mining Operations	MINING	Metallic Ore Mining (10)	2	Metal Mining
		Coal Mining (1211)		
Oil and Gas Extraction	OILGAS	Crude Oil Production, Storage, and Transfer (1211,4463)	3	Oil & Gas Extraction
		Natural Gas Production (1311)		
Mining Operations	MINING	Crushed Stone (142)	5	Nonfuel mining
		Sand and Gravel (144)		
		Clays (145)		
		Potash/Phosphate Rock (1474,1475)		
Degreasing	DEGRS	Degreasing	NA	Manufacturing
Misc. Industrial Processes	MISIND	Adhesives		
Indus. Organic Solvent Use, Misc.	SOLV	Other Organic Solvent Use		
		Solvent Extraction Processes		
Surface Coating	SRFCT	Surface Coating	NA	Durable Goods
Misc. Industrial Processes	MISIND	Lumber and Plywood (24)	11	Lumber & Wood Products
Cement Production	CEMNT	Cement (3241)	19	Stone, Clay, & Glass Products
Glass Manufacturing	GLASS	Glass (321,322)	19	Stone, Clay, & Glass Products
Lime Manufacturing	LIME	Concrete, Lime, Gypsum (327)	19	Stone, Clay, & Glass Products
		Lime (3274)		
Mineral Products Processing	MINRL	Clay Sintering (3295)	19	Stone, Clay, & Glass Products
		Brick and Tile (3251)		
Iron and Steel Production	IRNST	Iron and Steel (3312)	20	Primary Metal Industries
		Ferroalloys (3313)		
		Iron and Steel Foundries (332)		
Other Primary Metals Smelting	OTHMET		20	Primary Metal Industries
Primary Aluminum Smelting	PALUM	Primary Aluminum (3334)	20	Primary Metal Industries
Primary Copper Smelting	PCOPR	Primary Copper (3331)	20	Primary Metal Industries
Primary Lead and Zinc Smelting	PLDZC	Primary Lead and Zinc (3332,3333)	20	Primary Metal Industries
Other Sec. Metal Smelting and Refining	SECMET	Primary Nonferrous Smelters (333)	20	Primary Metal Industries
Other Sec. Metal Smelting and Refining	SECMET	Secondary Nonferrous Smelters (334,336)	20	Primary Metal Industries
Secondary Lead Refining	SLEAD	Secondary Lead (3341)	20	Primary Metal Industries
Food Proc. and Agric. Operations	FOODAG	Food and Beverages (20)	7	Food & Kindred Products
Misc. Industrial Processes	MISIND	Textiles (22)	9	Textile Mill Products
Paper and Pulp Mills Operations	PAPER	Pulp Mills (261,262)	13	Paper & Allied Products
Misc. Industrial Processes	MISIND	Graphic Arts (27)	14	Printing & Publishing
Printing Operations	PRINT		14	Printing & Publishing
Organic Chemicals Manufacture	ORGCM	Organic Chemicals (286)	15	Chemicals & Allied Products
		Carbon Black (2895)		
Other Chemicals Manufacture	OTHCM	Ammonia (2873)	15	Chemicals & Allied Products
		Nitric Acid (2873)		
		Chemicals (28)		
		Sulfuric Acid (2819)		
Petroleum Refining	PTREF	Petroleum Refining (2911)	16	Petroleum & Coal Products
		Asphalt Paving and Roofing (295)	16	Petroleum & Coal Products
Plastics Production	PLAST	Plastics (2821,3079)	17	Rubber and plastic products
Rubber and Misc. Plastics Manufacture	RUBR	Rubber Tires (3011)	17	Rubber and plastic products

Estimates of boiler fossil fuel consumption in 1980 for each State and major fuel type were provided by Hogan (Hogan, 1988). These estimates are based on the assumption that the industry mix, size, utilization, and AQCR distribution within a State are constant. Through assuming this relationship, the 1985 ICE base year was scaled to match the data for 1980, thus forming the 1980 interim base year data.

To construct the 1975 base year file, the assumption of a constant industry mix for a State and fuel type was no longer necessary, since detailed data on each industry for 1980 and 1975 were available from PURchased Heat And Power (PURHAPS) model data files (Werbos, 1983). These PURHAPS data files were derived from the Annual Survey of Manufactures: Fuels and Electric Energy Purchased for Heat and Power (DOC, 1991). The available data in these files were for *total* fuel use not *boiler* fuel use. To make use of these data, it was necessary to assume that the fraction of fuel used in boilers, for any given State and industry, remained constant from 1975 to 1980. To the extent that the fraction of boilers' heat versus process heat applications is a function of the specific industrial production process, this assumption is reasonable.

Based on the assumption of constant boiler fuel fraction of total fuel use, the ratio of 1975 to 1980 energy use for each State, industry, and fuel type was applied to the corresponding record of the 1980 interim base year file to produce 1975 base year files.

Control Scenario Industrial Process Emissions

To estimate boiler emissions of sulfur oxides (SO_x), NO_x, and VOC from industrial processes, data from *Trends* were used. The percentage change in national emissions by *Trends* category was applied to the appropriate sector from MSCET to obtain State-level emissions. In some cases there are several categories in *Trends* that match directly with MSCET categories (see Table B-1). In these cases, the *Trends* sectors were aggregated and the percentage change was computed. It was assumed that the level of control in each industry sector implied by *Trends* was uniform across States. The changes in emissions in each State are not equal to those at the national level, since the industry composition in each State varies.

Development of Economic Driver Data for the Control Scenario - Industrial Boilers and Processes

The results of the J/W model were the primary source of activity in the ICE model driver data. These results were also used by ELI to produce the national results for industrial processes from *Trends*. Both ICE and *Trends* use the forecasted change in industrial activity that results under the no-control scenario. These data were in the form of industry specific changes in energy consumption and industrial output, for boilers and industrial processes.

Economic Driver Data for Industrial Boiler Approach

Using the 1975 base year file as a starting point, the ICE model estimated fuel choice and emissions based on a user input file containing total boiler energy demand and regional energy prices. The 1975, interim 1980, and original 1985 base year files contained the required information on energy demand for each industry group and State, so the data in these three files were aggregated across fuel type, and other boiler characteristics (for example, size). These aggregated data provided the energy demand for three of the target years. Since 1990 State-level data on energy use by industry group were not available at the time of the study, the NAPAP base case forecast for the ICE model for 1990 was used to provide the demand data for this year.

The user input file for ICE also requires a price input for each target year. These prices were input by Federal Region for distillate oil, 4 grades of residual oil (by sulfur content), natural gas, and 11 grades of coal (by sulfur content and coal rank, i.e., bituminous and sub-bituminous). Prices for 1985 and 1990 were obtained from the NAPAP base case user input file. The prices for 1975 and 1980 are from U.S. Department of Energy (DOE) data on State-level industrial energy prices (DOE, 1990). Regional prices of natural gas, distillate oil, steam coal, and residual oil were constructed by aggregating expenditures across States within each region and dividing by total British thermal unit (BTU) consumption for the years 1975, 1980, and 1985. Since prices by sulfur content grade are not reported by this DOE source, ANL assumed that the sulfur premium implied by the 1985 ICE model input file was proportional to the average price. Based on this assumption, the ratio of the regional coal and residual oil price in 1975 and 1980 to the 1985 price was applied to the 1985 price in the ICE model base case file for each grade of fuel. To provide additional consistency between the NAPAP analysis and ANL's study, the distillate oil and natural gas prices were benchmarked to the 1985 ICE model prices as well.

One possible inconsistency arises using this procedure. The residual oil and natural gas markets are closely linked, particularly for industrial customers. These markets, specifically the gas market, underwent tremendous changes over the study period. To model the effect of these structural changes on the sulfur premiums in residual oil would require a detailed oil and gas supply model that was beyond the scope of this project. Moreover, the CAA regulations themselves create the potential for sulfur premiums. This potential effect of the CAA was not captured, though, because of the assumption of proportional fuel sulfur premiums on residual fuel oil. The relationship between market driven sulfur premiums in the coal market and the CAA was given additional consideration in this analysis through the use of an explicit coal supply model.

The J/W data for industrial energy consumptions was supplied in the form of percentage change in cost shares. In order to compute the percentage change in the quantity of energy used, ANL used the following identity:

$$1n\left(\frac{P_E \times E}{P_Q \times Q}\right) = 1n\,(P_E) + 1n\,(E) - 1n\,(P_Q \times Q), \text{ or} \quad (1)$$

$$1n\left(\frac{P_E \times E}{P_Q \times Q}\right) - 1n\,(P_E) + 1n\,(P_Q \times Q) = 1n\,(E), \text{ or} \quad (2)$$

The percentage change in E is the percentage change in cost share, minus the change in price, plus the change in value of shipments. These calculations were performed for each energy type and industry sector in the J/W model. The ICE model requires total fuel use, so the fuel specific percentages were weighted by historical fuel consumption to produce an aggregate change in fuel consumption to apply to the ICE model input data files.[9]

ICE also uses energy prices to simulate boiler fuel choices. The control scenario forecasts of energy prices in ICE were adjusted based on the percentage changes in energy prices, by coal, oil and natural gas. This implicitly assumes that the oil and coal fuel sulfur premiums, by region, are proportional to the average national price. To test this assumption for the coal market, additional modeling of the coal prices was performed using the coal market component of the ARGUS model.

It is possible that in some regions low sulfur coal prices to the industrial sector may be lower than the national average. This was not found to be the case. For example, in 1990, delivered regional industrial coal prices change by less than two-thirds of one percent. In most cases, the percentage change was near zero. This result appears to occur because of the highly regional nature of the coal market. While the artificial demand for low sulfur coal may fall, power plants near low sulfur coal reserves now find it advantageous to buy this local coal, which raises the price back to an equilibrium level near to that of the control scenario. This is even more likely to be true of industrial delivered prices, since industrial prices are more affected by transportation costs than are the utility prices. No additional ICE modeling was performed.

Economic Driver Data for the Industrial Process Approach

The J/W model was also used to account for activity level changes in the calculation of industrial process emissions under the no-control scenario. The correspondence between *Trends*, MSCET, and the J/W model was used to apply changes in industrial activity in each target year to each industrial process.

No-control Scenario Emissions

Industrial Boiler Emissions of SO_2, NO_x, and TSP

The CAA imposed different regulations, SIPs, and New Source Performance Standards (NSPS) that apply to industrial boilers of varying size. The primary effect of CAA regulations on industrial boilers was simulated by defining the Air Quality Control Region (AQCR), the resulting SIPs, and subsequent NSPS for boilers. The industrial boiler SIP regulations were included in the ICE base year file discussed in the previous section. Since the ICE model estimates new boiler emissions for each target year, the boiler NSPS are input through the ICE user files. Industrial NSPS were implemented in two phases. The 1971 regulations are imposed for the study years 1975 and 1980.

[9] ICE uses six of the manufacturing industries from the J/W model directly. The remaining industries' percentage changes were weighted to produce the "other" category.

The 1984 NSPS revisions are imposed in the study years 1985 and 1990. For the no-control scenario, ANL set the SIPs and NSPS to a flag that indicated "no regulation."

Industrial Boiler Emissions of CO and VOC

Two of the criteria pollutants emitted by industrial fuel combustors, CO and VOC, were not included as outputs of the ICE model. Therefore, CO and VOC emissions were analyzed separately using *Trends* methods. Control scenario CO and VOC emissions were taken directly from *Trends*.

To estimate CO and VOC emissions from industrial combustion for the no-control scenario, fuel use for industrial manufacturing was adjusted, reflecting fuel consumption changes estimated by the J/W model. These changes in the level of fuel consumption by industrial combustion were also used in ANL's ICE boiler model. Changes in industrial combustion fuel use by manufacturing between the control and no-control scenarios are reported in Table B-2. These estimates represent an average of several sectors, which were developed by ANL as part of the modeling process for ICE.

No-control scenario emissions were computed using 1970 emission factors. Since there were no add-on controls for industrial combustion VOC and CO emissions, it was not necessary to adjust the no-control scenario for changes in control efficiency.

Table B-2. Fuel Use Changes Between Control and No-control Scenarios.

Year	Fuel Type	Fuel Use Changes
1975	Coal	-.0042
	Oil	+.0311
	Gas	-.0064
1980	Coal	-.0061
	Oil	+.0107
	Gas	-.0095
1985	Coal	-.0061
	Oil	+.0089
	Gas	-.0097
1990	Coal	-.0079
	Oil	+.0091
	Gas	-.0099

Emission estimates were regionalized using State-level emissions data from industrial boilers recorded in MSCET. For the control scenario estimates, VOCs were regionalized using the MSCET State-level shares for industrial fuel combustion. In the no-control scenario, the State-level shares were held constant. The control scenario emissions of CO were regionalized using the control scenario NO_x emissions from the ICE model. This approach assumes that CO emissions are consistent with NO_x emissions. The no-control scenario CO emission estimates from industrial combustion sources were regionalized using no-control NO_x emission estimates from industrial combustion sources.

Industrial Process Emissions

A wide range of controls were imposed on industrial processes. These emission limits are embodied in the assumptions of control efficiencies in the *Trends* model. Data on national no-control scenario emissions from industrial processes were provided by EPA. These data were combined with MSCET to produce regional-level results.

Lead Emissions

Estimates of lead emissions from industrial boilers and industrial processes were completed by Abt Associates. The methods used for calculating lead emissions from industrial processes and industrial boilers were similar. The starting point was the TRI, which provides air toxics emissions data for manufacturing facilities with more than 10 employees. To estimate lead emissions from industrial boilers and processes, 1990 facility-level lead emissions data were extracted from the TRI. These data were then adjusted to create estimates of lead emissions from industrial sources under the control and no-control scenarios for each of the target years. For the control scenario, lead emissions for 1975, 1980, and 1985 were obtained by extracting an emission factor and a control efficiency for each lead-emitting industrial process in the *Trends* data base. These emission factors and control efficiencies were multiplied by the economic activity data for each year for each process as reported in *Trends* to yield estimated control scenario emissions by industrial process. Each industrial process was assigned a code to correspond with energy consumption data by industrial process compiled in the National Energy Accounts (NEA) by the Bureau of Economic Analysis, and emissions were summed over all processes to obtain a total for each target year.

For consistency with the other emission estimates in this analysis, industrial process no-control scenario lead emissions were adjusted for changes in industrial output, and for changes in emissions per unit of output due to control technology applications. Changes in industrial output were accounted for using results from the J/W model. Lead-emitting industrial processes in the *Trends* data base were assigned to a J/W sector. For each sector, the percentage change in economic output was used to adjust the economic activity data for that process from the *Trends* data base. These adjusted economic output figures were used with the 1970 emission factors and control efficiencies to derive the estimated no-control scenario lead emissions for each industrial process in each target year. The process-level emissions were then aggregated to the NEA-code level as in the control scenario.

The lead emission estimates from industrial processes, by NEA code, were used to derive percentage changes in emissions under the control and no-control scenarios by NEA code for application to the TRI emissions data. Since TRI data are reported by SIC code, NEA codes were "mapped" to the appropriate SIC codes, and then the percentage change for each NEA code was used to represent the percentage change for all SIC codes covered by that NEA code.

To calculate lead emissions from industrial boilers, Abt Associates developed estimates of lead emissions from industrial combustion under the CAA for each of the target years. The *Trends* data base contains national aggregate industrial fuel consumption data by fuel type. For each fuel type, the fuel consumption estimate was disaggregated by the share of that fuel used by each NEA industrial category. The *Trends* data base also contains emission factors for industrial fuel use, by fuel type, as well as control efficiencies. The lead emissions from industrial combustion for each NEA category were derived by multiplying the fuel-specific combustion estimate for each NEA category by the emission factor and control efficiency for that fuel type. The result was emissions of lead by NEA code and by fuel type. Emissions from all fuel types were then summed by NEA code. The NEA data were used to disaggregate the industrial fuel consumption figures, based on the assumption that the ICE are the same among all industries covered by a given NEA code.

To estimate no-control scenario lead emissions, the macroeconomic effect of the CAA and the change in emissions per unit of output that resulted from specific pollution control mandates of the CAA were both taken into account. As in the control scenario, the national aggregate industrial fuel consumption estimate by fuel type was disaggregated by the share of that fuel used by each NEA industrial category. The fuel use was then adjusted in two ways: some NEA codes were specifically modeled by the ICE model, and for the remaining NEA codes, J/W percentage changes in fuel use were applied. These fuel use estimates were then combined with the 1970 emission factors and control efficiencies for industrial combustion by fuel type from the *Trends* data base to obtain no-control scenario combustion-related lead emissions from industrial boilers by NEA code. These estimates of total lead emissions by NEA codes were matched to SIC codes, and then to the data in the TRI data base. This approach assumed that an average emission value was assigned to all reporting TRI facilities in a given SIC code.

Off-Highway Vehicles

The off-highway vehicle sector includes all transportation sources that are not counted as highway vehicles. Therefore, this sector includes marine vessels, railroads, aircraft, and off-road internal combustion engines and vehicles. As a whole, off-highway vehicle emissions are a relatively small fraction of total national anthropogenic emissions.

Overview of Approach

The process used by ELI to determine the national level of emissions from the off- highway transportation sector is similar to the procedure outlined above for industrial processes. To estimate the emissions of criteria air pollutants from these sources under the no-control scenario, the historical activity levels were held constant, rather than attempting to calculate a new no-control scenario level of off-highway vehicle activity. This assumption was necessary since the off-highway activity indicators (amount of fuel consumed, and landing and take-off cycles for aircraft) do not have direct correspondence with a given J/W category. The national no-control scenario emissions of criteria air pollutants from these sources were simply derived by recalculating emissions using 1970 emission factors.

Development of Control Scenario

To estimate control scenario emissions, the analysis relied on *Trends* methods, using historical activity indicators, emission factors, and control efficiencies. Essentially, the estimates of off-highway emissions under the control scenario represent the historical estimates from the *Trends* data base.

No-control Scenario Emissions Estimates

The calculation of off-highway emissions for the no-control scenario required the *Trends* data to be adjusted to reflect changes in controls and economic activity in each of the target years. Linking source activity changes with economic activity for this section is not straightforward. The economic activity data for off-highway engines and vehicles are expressed either in terms of amount of fuel consumed, or in terms of landing and take-off cycles for aircraft. Neither of these off-highway activity indicators has a direct correspondence with a given J/W sector, making the sort of direct linkage between *Trends* categories and J/W sectoral outputs that was used for industrial processes inappropriate.

In the absence of a link between the economic factors that are determinants of emissions from this sector and the available economic activity forecasts, the no-control scenario emissions of criteria air pollutants from off-highway mobile sources were estimated based on the same historical activity levels used for the control scenario. Although there were changes in sectoral output and personal income that might have had an effect on off-highway vehicle usage, these changes were deemed to be small and not likely to have a major effect on the emissions from this sector.

Emission factors for each of the off-highway sources were also held constant at 1970 levels to calculate no-control scenario emissions for each target year. The national emissions of criteria air pollutants from these sources were then recalculated using 1970 emission factors.

National and State-Level Off-Highway Emission Estimates

Table B-3 summarizes national-level emission estimates for off-highway sources. The emission estimates derived from using the methodology discussed above yielded results that seem counter-intuitive. The emissions from off-highway sources, in particular the emissions from aircraft, are lower in the no-control scenario than those projected for the control scenario for most pollutants. This is a result of calculating emissions using 1970 emission factors, since the 1970 emission factors for aircraft are lower than the aircraft emission factors in later years.

ELI identified several potential sources of uncertainty in the emission estimates for this sector. First, the assumption that the total level of off-highway vehicle fuel consumption is constant between the two scenarios may be flawed. Second, the use of 1970 emission factors in the no-control scenario may fail to capture significant changes in technology. These technological changes are implicitly captured in the control scenario and it is possible that these technological changes may also have occurred under a no-control scenario.

One possible response to the biases created by the use of 1970 emission factors for all years in the no-control scenario is to test how results might differ if the emission factors used for the control scenario, which would include technological change, were also used for the no-control scenario. However, using this treatment of emission factors, the emissions projections from the adopted methodology from non-highway sources in the no-control scenario would be identical to the emissions projections under the control scenario. The reason for this is that the economic activity levels were not adjusted for the calculation of emissions under the no-control scenario.

In order to disaggregate the national data to a State level, the methodology used the MSCET data base, which is described earlier. Emissions of VOC, SO_x, and NO_x were regionalized using the State-level shares from the MSCET methodology. The emissions of TSP were regionalized by using the State-level shares for SO_x reported by MSCET, and the emissions of CO were regionalized using the State-level shares for NO_x, also reported by MSCET. The potential bias that this introduces is likely to be small, due to the relative homogeneity of off-highway vehicle emission sources.

Table B-3. Difference in Control and No-control Scenario Off-Highway Mobile Source Emissions.

		1975	1980	1985	1990
TSP	Control Scenario:	268.6	281.1	268.7	280.9
	No-Control Scenario:	260.8	268.8	261.2	266.9
	Percentage Increase:	-3%	-4%	-3%	-4%
NO_x	Control Scenario:	1,987.6	2,176.7	2,077.5	2,085.9
	No-Control Scenario:	1,974.6	2,150.5	2,042.7	2,058.9
	Percentage Increase:	-1%	-1%	-2%	-1%
SO_2	Control Scenario:	364.6	531.1	406.4	392.5
	No-Control Scenario:	363.2	528.6	403.0	386.9
	Percentage Increase:	0%	0%	-1%	-1%
CO	Control Scenario:	8,512.8	8,101.4	7,881.9	8,079.0
	No-Control Scenario:	8,511.0	8,071.2	7,880.2	8,077.7
	Percentage Increase:	0%	0%	0%	0%
VOCs	Control Scenario:	1,374.9	1,370.8	1,334.8	1,405.0
	No-Control Scenario:	1,385.9	1,416.1	1,388.6	1,485.8
	Percentage Increase:	1%	3%	4%	6%

Note: Emission estimates are expressed in thousands of short tons. Percentage increase is the differential between scenarios divided by the Control Scenario projection.

As with regionalization of industrial process emissions, the State-level shares are held constant between the two scenarios. To the extent that the distribution of economic activity between States was not constant over the period of the analysis, holding State-level emission shares constant may bias the results, although the direction and magnitude of the potential bias is unknown.

On-Highway

This section addresses the highway vehicle portion of the transportation sector. Highway vehicle emissions depend on fuel type, vehicle type, technology, and extent of travel. Emissions from these vehicles have been regulated through Federal emission standards and enforced through in-use compliance programs, such as State-run emission inspection programs. Vehicle activity levels are related to changes in economic conditions, fuel prices, cost of regulations, and population characteristics. Emissions are a function of vehicle activity levels and emission rates per unit activity.

TEEMS was employed by ANL to analyze the transportation sector. The modeling system links several models, disaggregate and aggregate, to produce State-level estimates of criteria pollutants. The system is subdivided into two modules: an activity/energy module and an emissions module. Each module contains multiple models. TEEMS has been documented in several reports and papers (Mintz and Vyas, 1991; Vyas and Saricks, 1986; Saricks, 1985). It has been used for several policy analyses and assessment studies for DOE and NAPAP. This section presents an overview of the approach used to conduct the analysis of the transportation sector. Also included in this section is a summary of the methodology used by Abt Associates to estimate changes in lead emissions from highway vehicles in each target year.

Overview of Approach

TEEMS has two modules: an activity/energy module and an emissions module. The activity/energy module calculates emissions based on: (1) personal travel; (2) goods movement; and (3) other transportation activity inputs.

Personal Travel

Personal travel activity and resulting fuel consumption were calculated for each target year using procedures that disaggregate households by demographic and economic attributes. Economic driver data, developed from U.S. Government data and macroeconomic model(s) of the domestic economy, formed the basis for household disaggregation. Modeling procedures were employed by ANL to project movement of households between various attribute classes, and vehicle holdings were projected in terms of the number and type of vehicles held by each household type. National totals were then developed by aggregating the vehicle holding estimates for each household type, accounting for the number of households of that type. Travel estimates, in terms of VMT, were calculated using the same approach, and based on the VMT of each household type. The basis for household transportation activity projection has been empirically established through analysis of the 1983-84 Nationwide Personal Transportation Survey (NPTS) (FHWA, 1986; Mintz and Vyas, 1991). VMT are projected using this empirical relationship, and estimates of the elasticity of VMT to vehicle operating cost are then made. Energy consumption was estimated in each target year using VMT, shares of VMT by vehicle type, and exogenously developed vehicle characteristics.

The following three models and an accounting procedure were employed to develop target year personal travel activity projections:

1. The first model projected the target year distribution of households by their attributes. This model employed an iterative proportional fitting (IPF) technique and projected the number of households in each cell of the household matrix - each of which is defined by various categories within six household attributes.

2. The second model projected changes in vehicle ownership resulting from changes in income and cost of vehicle operation. The model applied estimated ownership changes to each target year household matrix such that the control values within each of the household attributes, excepting vehicle ownership, remained unchanged.

3. The third model estimated the composition of household vehicle fleet by type (cars and trucks), size, technology, and fuel.

4. An accounting procedure applied VMT per vehicle to vehicle ownership in each combination of household attributes. VMT and energy consumption were accumulated by vehicle type, size, and fuel.

Each of these models is described separately in the following subsections.

Iterative Proportional Fitting (IPF)

This IPF model modified a control scenario matrix of household counts. A household matrix was developed from the 1983 NPTS data and upgraded to the year 1985 using published aggregate data. The procedure used in constructing the 1985 household matrix has been documented elsewhere (Appendix B of Mintz and Vyas, 1991). The matrix is defined by six attributes: (1) residential location (central city, suburb, rural); (2) household income; (3) age of householder; (4) household size; (5) number of drivers; and (6) number of vehicles. The household matrix has 3,072 cells, some of which are illogical (such as 1 person, 2 drivers). Illogical cells were replaced with zeros.

Household shares within each attribute in each target year were developed exogenously using data from the Bureau of the Census and selected macroeconomic model runs. The projected total of households and shares of households in each category of an attribute were supplied to the IPF model. The model modified the control scenario household matrix to match the specified shares and total number of households.

The IPF model treated household distribution within each attribute as a set of vectors. These vectors were scaled to match the specified shares and household total. Following the initial scaling, a gradual scaling technique was used to move in the direction of the target shares. The scaling process was repeated until closure was achieved for all attribute classes. Since vehicle ownership levels were estimated by the vehicle ownership model (described in the next section), shares within the sixth household attribute (number of vehicles held) were not specified, leaving it uncontrolled. This flexibility of an uncontrolled attribute helped to facilitate the model operation. The number of households in each class of vehicle ownership within the output matrix represents distribution of households using the control scenario (1985) relationship of vehicle ownership to other household attributes.

Vehicle Ownership Projection (VOP)

The VOP model projected the changes in vehicle ownership resulting from changes in the number of licensed drivers, disposable personal income, and annual fuel cost of vehicle operation. The model is based on historical household ownership rates. A target per-driver ownership rate was computed using disposable income and fuel cost. This target rate represented desired ownership if income and fuel cost were the only determinants. A parameter representing ownership responsibilities such as acquisition effort, disposal effort, parking requirements, and other indirect aspects was applied to adjust this target. The new ownership rate was used to estimate the number of household vehicles.

The household matrix created by the IPF model was revised to match the projected household vehicle ownership. Household shares within the first five attributes remain constant while those within the sixth attribute (i.e., number of vehicles) were variable. A deviation measure was defined and its value for each class within the first five attributes was minimized. A set of simultaneous equations was solved using Lagrangian multipliers.

Projection of Vehicle Fleet Composition

The composition of household vehicles was projected for each household matrix cell using a vehicle choice model called the Disaggregate Vehicle Stock Allocation Model (DVSAM). Vehicles are defined by type (auto, light truck), size (small, mid-size, full-size auto; small pickup, small utility/minivan, standard pickup, large utility/standard van; or any other size classification), fuel (gasoline, diesel, methanol, ethanol, or compressed natural gas), and technology (stratified charge, direct injection, electric, fuel cell, or Brayton).

The model computed vehicle composition based on an individual vehicle's utility to households and household needs. A menu of vehicles classified by the previously mentioned vehicle attributes was supplied to the model. The menu specified characteristics of each vehicle available to households. Vehicles were characterized by price, operating cost, seating capacity, curb weight, and horsepower. These variables formed the basis for computing "utility" (analogous to consumer satisfaction). The household matrix provided demographic and economic attributes which, when combined with vehicle usage in miles, define household needs. Vehicle usage (VMT) was computed as a function of income, number of drivers, and number of vehicles. A logit model was applied to compute vehicle ownership shares. Several model enhancements facilitated modeling of limited range vehicles, and representation of supply constraints and/or regulated market penetration.

Activity/Energy Computation

An accounting procedure was applied to compute personal travel activity in terms of VMT by vehicle type. Control scenario VMT per vehicle estimates for each cell in the household matrix were developed from the 1983 NPTS. These rates were adjusted within the procedure on the basis of changes in average vehicle operating cost per mile for each cell. The vehicle composition projection model computes ownership shares and share-weighted change in vehicle operating cost. Elasticity values were applied to this change.

ANL assumed that VMT per vehicle remained nearly unchanged for a household matrix cell over time (with the exception of the effect of changes in vehicle operating cost). In other words, variation of VMT across household types is far greater than within household types. VMT per household vehicle remained stable during the period from 1977 to 1984 (Klinger and Kuzmyak, 1986). Some increases were observed in recent years, which were attributed to lower fuel prices and increased household income (DOC, 1991; FHWA, 1992). (A portion of the increase could be attributed to the method of computing average VMT per vehicle.) The assumption that VMT per vehicle for each cell remained nearly constant and was elastic relative to vehicle operating cost is reasonable. As households move from one cell of the matrix to another, they "acquire" the VMT per vehicle rate of that cell. Thus, this approach accounted for changes in VMT per vehicle due to increased household affluence, increased rate of driver licensing, changes in fuel price, and changes in vehicle technology.

Goods Movement

Energy and activity demand resulting from movement of 24 aggregate categories of commodities is estimated by this subcomponent of the TEEMS activity module. Changes in commodity demand/production were provided by growth indexes by two-digit SIC generated by a macro model. A model that projects shifts in mode shares among truck, rail, marine, air, and pipeline modes was used, followed by a procedure to compute ton miles of travel for each mode, VMT by fuel type for trucks, and energy consumption by operation type for non-highway modes. The model used 1985 control scenario data, which were compiled from railroad waybill sample and publications, waterborne commerce publications, transportation statistics, and other sources. The procedure used in developing the 1985 control scenario freight data has been documented in an ANL report (Appendix A of Mintz and Vyas, 1991).

This goods movement model was not used for this retrospective analysis because of funding and time constraints. A procedure to estimate truck VMT by fuel type was employed in its place. Published historical VMT values (FHWA, 1988; 1992) were used along with VMT shares by fuel and truck type from Truck Inventory and Use Surveys (TIUS) (DOC, 1981; 1984; 1990).

Other Transportation Activities

The activity/energy module also has other models for developing activity and energy use projections for air, fleet automobiles, and bus modes. Fleet automobile activity estimates from an earlier study (Mintz and Vyas, 1991) were used while other modes were not analyzed.

Lead Emissions

Estimates of lead emissions in the transportation sector were developed by Abt Associates based on changes in reductions of lead in gasoline. This estimation required the estimates of lead in gasoline consumed over the period from 1970 to 1990 and the amount of lead content in gasoline that would have been consumed in the absence of the CAA. These values were calculated using the quantity of both leaded and unleaded gasoline sold each year and the lead concentration in leaded gasoline in each target year. Data on annual gasoline sales were taken from a report by ANL that presented gasoline sales for each State in each target year. For the control scenario, data on the fraction of gasoline sales represented by leaded gasoline were used. For the no-control scenario, all of the gasoline sold was assumed to be leaded. Data on the lead content of gasoline was obtained from ANL for 1975 through 1990. For 1970 through 1975, the analysis assumed that the 1974 lead content was used.

Estimation of No-control Scenario Emissions

TEEMS emissions projections were carried out by ANL in the following three steps:

1. Development of emission factors;
2. Allocation of highway activity to States; and
3. Development of highway pollutant estimates.

The following subsections describe the procedures used for computing highway vehicle emissions.

Development of Emission Factors

EPA's MOBILE5a Mobile Source Emission Factor model was used to provide all of the highway vehicle emission factors used to estimate 1975 to 1990 emission rates (EPA, 1994b). Documentation of the MOBILE5a model is found in the User's Guide for the MOBILE5 model.[10]

Although the actual emission factors used by ANL are not documented in either the original ANL TEEMS model report or in the Pechan summary report, the Project Team provided direction that defined the emission factors to be used. For the control scenario, ANL was directed to use the official EPA emission factors prevailing at the time for each target year. For example, the official EPA emission factor being used in 1980 for on-highway vehicle NO_x was to be used to estimate 1980 control scenario on-highway vehicle NO_x emissions. For the no-control scenario, the official EPA emission factors used to estimate emissions in 1970 were to be used throughout the 1970 to 1990 period.

It is important to note that using the 1970 on-highway vehicle emission factors to estimate no-control scenario emissions for the entire 1970 to 1990 period may bias scenario emission differentials upward. This is because it is possible that technological changes to on-highway vehicles unrelated to CAA compliance

[10] EPA/OAR/OMS, "User's Guide to MOBILE5," EPA-AA-AQAB-94-01, May 1994; see also 58 FR 29409, May 20, 1993.

strategies may have yielded incidental reductions in emissions. However, EPA Office of Mobile Sources (EPA/OMS) experts indicate that the two major technological changes in vehicles occurring during the period of the analysis –electronic ignition and electronic fuel injection– would have yielded negligible emission reductions in the absence of catalytic converters.[11]

Another potential bias is introduced by assuming the CAA had no substantial effect on vehicle turnover. However, two factors render this potential bias negligible. First and foremost, under the no-control scenario retired vehicles would be replaced by new but equally uncontrolled vehicles. Second, no-control scenario vehicle use is greater in terms of VMT per year. This means no-control scenario vehicles would reach the end of their service lives earlier, offsetting to some extent the alleged incentive to retire vehicles later due to costs imposed by CAA control requirements.

Allocation of Highway Activity to States

TEEMS' activity module generated national activity and energy estimates. These activity totals were allocated to States through a regionalization algorithm that used time series data on historical highway activity shares by State. A trend extrapolation methodology was used that stabilizes shifts after 5 years in the future. For the retrospective analysis, historical highway activity shares for each target year were developed using data published by the Federal Highway Administration (FHWA) (FHWA, 1988; 1992).

Development of Highway Pollutant Estimates

Highway emission estimates were calculated in both scenarios for each target year using VMT estimates generated by TEEMS and emission factors from MOBILE5a. Control scenario activity levels were adjusted for the no-control scenario using economic forecasts and historical data.

Control Scenario Emissions Calculation

Control scenario data for the transportation sector were compiled from several sources. Household counts and shares of households by six attributes were obtained from various editions of the *Statistical Abstracts* of the United States. Household income information was obtained from the control scenario run of the J/W model. Fuel prices were obtained from the *Annual Energy Review* (DOE, 1992) while vehicle fuel economy and aggregate VMT per vehicle were obtained from *Highway Statistics* (FHWA, 1988; 1992). B-4 lists data sources for the control scenario run.

Table B-5 shows household shares prepared for the IPF model. The total number of households increased from 63.4 million in 1970 to 93.3 million in 1990. A gradual shift from rural to urban was observed with movement to suburbs within urban areas. The effect of economic downturns in 1975 and 1980 was an increase in share for the lowest income category; more households moved to the highest income group from 1970 to 1990, while the lower middle income group share expanded and the upper middle income share declined. The rate of household formation was high during the 1970's, which resulted in increases in smaller and younger households. The trend in younger households reversed after 1980 as household formation slowed. Average household size dropped from 3.2 in 1970 to 2.67 in 1990. The number of licensed drivers increased throughout the analysis period as more and more young people were licensed to drive.

Data for the VOP model included disposable income per capita, fuel price, overall personal vehicle fuel economy, and annual usage in terms of VMT. Table B-6 shows these data for each year in the analysis period.

Data preparation for the model that projected household vehicle composition was limited to characterization of existing technology vehicles. Seven vehicle size and type combinations were characterized for 1975 and 1980 while one vehicle, minivan/small utility, was added for 1985 and 1990. Control scenario vehicle characteristics are tabulated in Table B-7. TEEMS' activity and energy computation procedure was executed to produce personal vehicle travel and energy consumption estimates.

Commercial truck travel was not modeled but, historical data published by the FHWA (FHWA, 1987; 1991) were used. FHWA publishes truck travel by three categories: 1) 2-axle, 4-tire trucks; 2) single unit

[11] Telephone conversation between Jim DeMocker, EPA/OAR and EPA/OMS/Ann Arbor Laboratory staff (date unknown). Nevertheless, the Project Team did consider reviewing emission factors for European automobiles to attempt to estimate no-control scenario emission factors for 1975 through 1990 reflecting the use of electronic fuel injection and electronic ignition but no catalytic converter. However, the Project Team concluded that differences in fuel/air mix ratios used in Europe would probably obscure any differences in emission rates attributable to the use of electronic fuel injection and electronic ignition.

trucks; and 3) combination trucks. All 2-axle, 4-tire trucks were treated as light-duty trucks. VMT by personal light trucks were subtracted from the published totals to arrive at commercial light truck VMT. Diesel truck VMT shares of total VMT were obtained from TIUS (DOC, 1981; 1984; 1990). TIUS data were also used to split VMT by single unit and combination trucks. All combination trucks were assumed to be the heaviest, class 7 and class 8, while single unit trucks could be of any size class 3 through 8. Gasoline and diesel VMT totals were developed for these heavy-duty trucks and were kept constant for the control and no-control scenarios.

Table B-4. Sources of Data for Transportation Sector Control Scenario Activity Projection.

Data Item	Model	Source
Household total, population, household shares by four attributes (location, income, age of head, and household size).	IPF	Statistical Abstract of the United States, editions 96th, 98th, 103rd, 104th, 108th, and 113th.
Household shares by number of drivers.	IPF	Statistical Abstracts and FHWA Highway Statistics provided total drivers. The *with CAA* distribution of households trended.
Personal and Disposable income.	VOP	J/W model output and Statistical Abstracts.
Vehicle fleet on-road fuel economy.	VOP DVSAM	FHWA Highway Statistics.
Fuel Prices	VOP DVSAM	Energy Information Administration's (EIA) Annual Energy Review.
Vehicle Price	DVSAM	Ward's Automotive Yearbooks 1975-1983, Automotive News Market Data Book 1985.

IPF - Iterative Proportional Fitting
VOP - Vehicle Ownership Projection
DVSAM - Disaggregate Vehicle Stock Allocation Model
FHWA - Federal Highway Administration
EIA - Energy Information Administration

Table B-5. Distribution of Households by Demographic Attributes for Control Scenario.

Household (Million)	63.4	71.1	80.8	86.8	93.3
Population (Million)	204.0	215.5	227.2	237.9	249.5
Attribute	**Household Percentage, by Year**				
	1970	1975	1980	1985	1990
Location					
Central City	33.2	32.0	31.9	31.6	31.4
Suburbs	33.6	36.0	37.0	38.1	38.3
Rural	33.2	32.0	31.1	30.3	30.3
Income (1990 $)*					
<$13,000	25.9	26.5	26.6	25.9	25.5
$13,000 - $33,000	34.0	37.2	37.4	37.7	38.0
$33,000 - $52,500	27.6	22.7	22.4	22.2	22.2
>$52,500	12.5	13.6	13.6	14.2	14.3
Age of Householder (YR)					
<35	25.4	29.1	31.1	29.3	27.4
35 - 44	18.6	16.7	17.3	20.1	22.1
45 - 64	36.3	34.0	31.2	29.6	29.0
> = 65	19.7	20.2	20.4	21.0	21.5
Household Size					
1	17.2	19.5	22.7	23.7	24.6
2	29.0	30.7	31.3	31.6	32.2
3 - 4	33.0	33.0	33.2	33.5	32.8
> = 5	20.8	16.8	12.8	11.2	10.4
Licensed Drivers					
0	9.1	8.5	8.1	7.2	6.6
1	27.8	27.3	27.0	26.2	26.0
2	48.1	49.2	50.5	52.5	53.5
> = 3	15.0	15.0	14.4	14.1	13.9

Note: *Approximated to 1990 dollars.

Table B-6. Economic and Vehicle Usage Data for Vehicle Ownership Projection – Control Scenario.

Year	Disposable Income per Capita (84 $)	Fuel Price (84 $)/Gallon	Miles/Gallon	VMT/Vehicle
1970	7,597	0.92	13.5	10,143
1971	7,769	0.88	13.5	10,246
1972	7,990	0.84	13.4	10,350
1973	8,436	0.84	13.3	10,184
1974	8,270	1.06	13.4	9,563
1975	8,340	1.03	13.5	9,729
1976	8,553	1.02	13.5	9,833
1977	8,742	1.01	13.8	9,936
1978	9,070	0.97	14.0	10,143
1979	9,154	1.21	14.4	9,522
1980	9,052	1.53	15.5	9,212
1981	9,093	1.55	15.9	9,212
1982	9,050	1.38	16.7	9,419
1983	9,239	1.27	17.1	9,419
1984	9,691	1.20	17.8	9,550
1985	9,881	1.09	18.2	9,568
1986	10,139	0.88	18.3	9,672
1987	10,174	0.88	19.2	10,090
1988	10,564	0.86	19.9	10,100
1989	10,713	0.90	20.3	9,819
1990	10,903	1.00	20.8	9,780

Table B-7. Control Scenario Personal Characteristics.*

Vehicle Type and Size (Seats)	1975 Curb Weight (lb)	1975 Engine Power (hp)	1975 Fuel Economy (mpg)	1980 Curb Weight (lb)	1980 Engine Power (hp)	1980 Fuel Economy (mpg)
Automobile						
Small (2-4)	2,770	91	17.2	2,535	83	19.6
Compact (4)	3,625	115	14.6	3,335	105	16.9
Mid-size (5)	4,140	128	13.3	3,730	116	15.1
Large (6)	4,900	155	12.2	4,840	153	13.3
Light truck						
Std. truck	4,530	141	11.2	4,455	143	12.6
Compact	3,745	108	14.2	3,580	99	15.9
Std. Van/Std.	5,010	145	9.9	4,975	144	11.4
Utility (11-15)						
Minivan/Small Utility (7-8)						

Vehicle Type and Size (Seats)	1985 Curb Weight (lb)	1985 Engine Power (hp)	1985 Fuel Economy (mpg)	1990 Curb Weight (lb)	1990 Engine Power (hp)	1990 Fuel Economy (mpg)
Automobile						
Small (2-4)	2,225	75	22.7	2,135	75	24.9
Compact (4)	2,775	90	19.3	2,595	90	22.0
Mid-size (5)	3,180	108	16.8	3,050	108	19.5
Large (6)	3,975	135	14.6	3,705	130	17.1
Light truck						
Std. truck	4,160	132	13.1	4,000	128	14.1
Compact	3,495	90	17.2	3,360	90	18.9
Std. Van/Std.	4,920	142	12.4	4,765	138	12.9
Utility (11-15)						
Minivan/Small Utility (7-8)	4,125	101	16.7	3,910	108	18.2

Note: *Average for all vehicles of each type and size.

Table B-8. Distribution of Households by Income Class for No-control Scenario.

	Household Shares (%), by Year			
Attribute	**1975**	**1980**	**1985**	**1990**
Income (1990 $)*				
<$13,000	26.3	26.2	25.3	24.7
$13,000-33,000	37.3	37.6	38.4	38.4
$33,000-52,000	22.8	22.6	22.0	22.6
>$52,000	13.6	13.6	14.3	14.3

Note: *Approximated to 1990 dollars.

No-control Scenario Emissions

The control scenario data were modified to reflect no-control scenario emissions using economic changes predicted by the J/W model, EPA, and ANL. The J/W model predicted a slight loss of employment and drop in GNP in terms of nominal dollars. However, the lower rate of inflation coincided with a real GNP rise. ANL's information from the model did not include any indexes for converting nominal income to real income. ANL assumed real income changes to be similar to those of real GNP and modified household shares by income classes accordingly. The model also predicted a slight drop in refined petroleum price beginning in 1973. The predicted drop was the largest (5.35 percent) in 1973, reached the lowest level (2.16 percent) in 1984, then increased to a second peak (3.44 percent) in 1988, and dropped again from 1989 to 1990. Since these changes were inconsistent with historical patterns of leaded and unleaded gasoline price change, ANL developed an estimate of changes in fuel price resulting from the cost of removal of lead from gasoline and other infrastructure costs involved with distributing a new grade of fuel. Subsequently, EPA provided a set of fuel costs for use in the analysis. Both ANL and EPA fuel prices followed a similar pattern, although their magnitudes differed. The no-control scenario was analyzed with EPA fuel prices. ANL also established a relationship with cost of regulation/emission control technology, and the effect of costs on vehicle price and fuel economy directly from the EPA publication *Cost of A Clean Environment* (EPA, 1990). These changes were used in the analysis.

The IPF model was executed for target years 1975, 1980, 1985, and 1990 using a set of revised household shares by income class. Table B-8 shows the revised shares. Comparing Table B-8 no-control scenario shares with those in Table B-5 for the control scenario, there seems to be a slight shift away from travel by the lowest income group and toward the middle income groups.

The vehicle ownership projection model was executed for the above four target years using the data listed in Table B-9. Changes in fleet characteristics are summarized in Table B-10.

Table B-9. Economic and Vehicle Usage Data for Vehicle Ownership Projection – No-control Scenario.

Year	Disposable Income per Capita (84 $)	Fuel Price (84 $)/Gallon	Miles/ Gallon	VMT/Vehicle
1970	7,597	0.91	13.5	10,143
1971	7,769	0.88	13.5	10,247
1972	7,990	0.83	13.4	10,353
1973	8,463	0.84	13.3	10,189
1974	8,297	1.06	13.4	9,569
1975	8,406	1.02	13.5	9,736
1976	8,600	1.01	13.5	9,854
1977	8,795	1.01	13.8	9,963
1978	9,126	0.96	14.0	10,174
1979	9,216	1.19	14.4	9,557
1980	9,114	1.51	15.5	9,234
1981	9,158	1.53	16.0	9,234
1982	9,116	1.36	16.8	9,447
1983	9,312	1.25	17.2	9,450
1984	9,775	1.18	17.9	9,582
1985	9,976	1.06	18.3	9,607
1986	10,244	0.84	18.4	9,738
1987	10,282	0.86	19.4	10,201
1988	10,676	0.83	20.1	10,214
1989	10,827	0.88	20.5	9,902
1990	11,019	0.97	21.0	9,849

Note: The effect of reductions in vehicle price and vehicle operating cost, and increases in fuel economy and horsepower were reflected in the menu of the vehicle choice model (DVSAM). Vehicle weight and seating capacity were kept unchanged from the *with CAA* run. Table IV-7 shows the changes in various vehicle attributes.

Table B-10. Percent Changes in Key Vehicle Characteristics Between the Control and No-control Scenarios.

	1975			1980		
Vehicle	**Price**	**mpg**	**HP**	**Price**	**mpg**	**HP**
Small Auto	-2.35	0.01	0.59	-2.76	0.22	1.81
Compact Auto	-2.35	0.01	0.59	-2.76	0.22	1.81
Midsize Auto	-2.35	0.01	0.59	-2.76	0.22	1.81
Large Auto	-2.35	0.01	0.59	-2.76	0.22	1.81
Small Truck	-1.30	0.01	0.59	-2.71	0.22	1.81
Std Truck	-1.30	0.01	0.59	-2.71	0.22	1.81
Std Van/Util	-1.30	0.01	0.59	-2.71	0.22	1.81
M Vn/Sm Utility						

	1985			1990		
Vehicle	**Price**	**mpg**	**HP**	**Price**	**mpg**	**HP**
Small Auto	-3.25	0.62	2.20	-2.94	0.95	2.77
Compact Auto	-3.25	0.62	2.20	-2.94	0.95	2.77
Midsize Auto	-3.25	0.62	2.20	-2.94	0.95	2.77
Large Auto	-3.25	0.62	2.20	-2.94	0.95	2.77
Small Truck	-2.53	0.62	2.20	-2.58	0.95	2.77
Std Truck	-2.53	0.62	2.20	-2.58	0.95	2.77
Std Van/Util	-2.53	0.62	2.20	-2.58	0.95	2.77
M Vn/Sm Utility	-2.53	0.62	2.20	-2.58	0.95	2.77

Note: *Average change for each vehicle size and type combination.

Utilities

The electric utility industry retrospective analysis was prepared using two different utility simulation models. ICF utilized its CEUM to estimate control and no-control scenario emissions for SO_2, TSP, and NO_x in each of the target years. ANL's ARGUS model was used to estimate electric utility CO and VOC emissions for the same period. This mix of modeling approaches was used because, while CEUM was determined to be a better tool for examining fuel shifts that were affected by the CAA than ARGUS, the CEUM model was not initially set-up to evaluate CO or VOC emissions. Although CEUM can be (and eventually was) configured to provide emission estimates for pollutants other than SO_2, NO_x, and PM, ARGUS was already configured to provide VOC and CO emissions. However, it should also be noted that VOC and CO emissions from utilities are quite low, as efficient fuel combustion reduces both pollutants. Thus, for this sector, the presence or absence of the CAA would not produce any different VOC or CO control techniques. VOC and CO emission rates for this sector differ primarily based on the fuel and boiler type. Therefore, a simpler modeling approach was judged to be acceptable and appropriate for these two pollutants. This chapter presents the methodology used to estimate utility emissions under the control and no-control scenario using the CEUM and ARGUS models. The method used by Abt Associates to estimate lead emissions from utilities is also presented.

Overview of Approach

The CEUM model uses industry capacity data and specific unit-by-unit characteristics, operating costs data, electricity demand estimates under the control and no-control scenario, and historical fuel prices to estimate SO_2, TSP, and NO_x emissions for 1980, 1985, and 1990. Changes in electric utility emissions, costs, and regional coal production were developed using ICF's CEUM with a calibration to historical electricity generation, fuel use, and emissions. The ARGUS model, which was used by ANL to estimate utility VOC and CO emissions, is driven by operating costs, industry capacity and generation data, demand for coal, and unit-level operating characteristics. The J/W model is used to incorporate predicted changes in electricity demand under the no-control scenario. Finally, Abt Associates relied upon energy use data, the *Trends* data base, and the Interim 1990 Inventory to calculate utility lead emissions based on coal consumption. The approaches used by each of these three contractors are discussed individually in the following sections.

Establishment of Control Scenario Emissions

A common feature of the approaches taken by ICF and ANL was to identify conditions that are inputs to the CEUM and ARGUS models, respectively, in the control scenario. Later in the analysis, these variables were revised to reflect no-control scenario conditions. The next section discusses the specific assumptions used in the CEUM analysis.

Key Assumptions in the Development of the ICF Analysis

At EPA's direction, ICF made several assumptions in conducting this analysis for purposes of consistency with other ongoing EPA efforts assessing the effects of the CAA. These include the macroeconomic assumptions regarding the effects of the CAA on economic growth, or more specifically, electricity demand, developed from other EPA commissioned efforts. Each is described briefly below.

Pollution Control Equipment Costs

Only limited actual data were available for this analysis on the historical capital and operating costs of pollution control equipment. Accordingly, for this analysis, the actual capital and operating costs of scrubbers were estimated using EPA scrubber cost assumptions adjusted to reflect actual data from a survey of scrubbed power plants with scrubbers installed during the 1970s and early 1980s. For those power plants with actual survey data, actual capital costs were used. For other pre-1985 scrubbers, ICF relied on the average costs from the survey data. For particulate control equipment (primarily electrostatic precipitators, or ESPs), costs were estimated based on limited actual data, and a 1980 Electric Power Research Institute (EPRI) study of ESP and baghouse costs. Based on this information, ESPs were estimated to cost an average of $50 per kilowatt (in 1991 dollars). The development of more detailed data on actual power plant pollution control costs was beyond the scope of ICF's analysis. ICF concluded that such an effort would not significantly change the national or regional cost estimates developed by its approach.

Electricity Demand and Fuel Prices

Consistent with other EPA ongoing analyses, ICF assumed that the CAA resulted in a reduction in electricity demand of 3.27 percent in 1980, 2.77 percent in 1985, and 2.97 percent in 1990. Also consistent with these studies, ICF assumed that natural gas prices and oil prices would not be affected by the CAA. Coal prices were estimated to change in line with increases and decreases in demand for specific coal supplies (and consistent with ICF's detailed modeling of coal supply and demand). The average prices of all residual oils consumed were also estimated to change due to a greater use of more expensive lower sulfur residual oils under the CAA.

Coal, Nuclear, Hydro, and Oil/Gas Capacity

At EPA's direction, ICF's approach was based on the assumption that no changes in the amount of nuclear, coal, hydro, or oil/gas stream or combined cycle capacity would be built or in place in 1980, 1985, or 1990. Given that the driving factors associated with the actual decisions to build new baseload capacity were not based solely on economics but entailed financial, regulatory, and political factors as well, the actual effect of the CAA on these build decisions is very uncertain. To the extent that more coal-fired power plants would be built and fewer oil/gas-fired power plants constructed, the actual emissions reductions associated with the CAA would be greater than those estimated by ICF, while the estimated costs of the CAA would be greater (because fewer, lower-cost, coal-fired power plants would be on line under the CAA). However, the CAA had virtually no effect on the costs of constructing new coal-fired power plants that came on line prior to about 1975 and a relatively moderate cost effect on coal-fired power plants that came on line through the early 1980s (since these power plants were not required to install scrubbers). Since a large majority of coal-fired power plant capacity came on line prior to 1975, ICF concluded that the effect of the CAA on the amount of total coal-fired capacity was not expected to be very large.

Natural Gas Consumption

The analysis assumed that the amount of natural gas consumed under the no-control scenario could not exceed the actual amount of consumption in 1980, 1985, and 1990. In part, because of natural gas price regulation and the oil price shocks of the 1970s, natural gas was often unavailable to electric utilities in the early 1980s. Since the CAA is relatively unrelated to the questions of supply availability and price regulation of natural gas, ICF assumed that no additional gas supplies would be available if the CAA had never been adopted. It is possible, however, that in the absence of the CAA, industrial and commercial users of natural gas would have used more oil or coal. To the extent that this would have occurred, there would have been more natural gas supplies available to the electric utility sector. This increase in supply would have resulted in an increase in the estimated costs of the CAA, and a corresponding decrease in the estimated emission reductions. ICF concluded, however, that this effect would not be very significant.

State and Local Environmental Regulations

At EPA's direction, ICF assumed that there would be no State and local emission limits or other emission control requirements under the no-control scenario. Accordingly, ICF assumed that there would be no SO_2, NO_x, or TSP emission limits under the no-control scenario and that all scrubbers, NO_x controls, and ESPs/baghouses (at coal-fired power plants) were installed as a result of the CAA. (The more limited amount of particulate control equipment installed at oil-fired plants was assumed to have been installed prior to the passage of the CAA.) In the case of particulate control equipment, some ESPs and other equipment were installed at coal plants prior to the 1970 CAA. To the extent that this is the case, the estimates of the costs of meeting the CAA have been overstated. ICF concluded, however, that the amount of such capacity was not substantial.

Retirement Age

The analysis assumed that unit retirement age was constant between the control and no-controls scenarios. Adoption of this assumption might bias the emission reduction estimates upward to the extent turnover rates of older (and presumably higher-emitting) units may be slower under the control scenarios, because more significant CAA control requirements focused on new units. However the vast majority of existing coal and oil capacity was built after 1950 and it is generally acknowledged that a relatively short technical plant lifetime would be about 40 years. As such, even if the no-control scenarios resulted in no life-extension activity, there would be virtually no effect over the 1970 to 1990 timeframe of the analysis.

ICF 1975 Control Scenario Emissions

The 1975 emissions under both scenarios were calculated differently than emissions in 1980, 1985, and 1990. In calculating or estimating 1975 SO_2 emissions for the control scenario (i.e., "actual" 1975), the weighted average emission rates at the State level, in the year 1975 were estimated, based on plant level average sulfur content of fuel deliveries from Federal Energy Regulatory Commission (FERC) Form 423 and assumed AP-42 sulfur retention in ash. These weighted average emission rates were then applied to actual State-level electric utility fuel consumption in the year 1975 (DOE, 1991). In the case of NO_x emissions, first, an estimate of Statewide NO_x emissions in the year 1975 was derived based on the use of the same NO_x emission rates, by fuel type, as developed for the 1980 no-control scenario modeling runs. These emission rates were specific to the fuel type (coal, oil, or natural gas). These Statewide NO_x emission rates or factors were then applied to actual fuel consumed by electric utilities in the year 1975, in order to obtain estimated "actual" 1975 emissions. As before, the fuel consumption at a State level was derived from the *State Energy Data Report* (DOE, 1991). ICF calculated the weighted average heat content (BTU/lb) by State from the 1975 FERC Form 423 data and used these figures with the TSP emission factors (lbs/ton) to derive emission rates by State (lbs/MMBTU). These emission rates were then applied to 1975 fuel consumption estimates obtained from the *State Energy Data Report*. For the control scenario 1975 estimates, ICF used the 1975 factors.

For the remaining target years, ICF used the results of CEUM runs that provided fuel consumption figures in 1980, 1985, and 1990, respectively. Emissions were then calculated using the appropriate emission factors for each year.

ARGUS Modeling Assumptions

The portion of the electric utility sector analysis conducted by ANL with the ARGUS model is described in this subsection. ARGUS contains four major components: BUILD, DISPATCH, the Emissions and Cost Model, and the Coal Supply and Transportation Model (CSTM). An overview of ARGUS can be found in Veselka *et al* (1990). Only the DISPATCH and CSTM modules were used for the present analysis. A brief description of the ARGUS components used in this analysis is found in the following subsections.

DISPATCH Module

The DISPATCH module contains a probabilistic production-cost model called the Investigation of Costs and Reliability in Utility Systems (ICARUS). This module calculates reliability and cost information for a utility system. ICARUS represents detailed, unit-by-unit operating characteristics such as fuel cost, forced outage rate, scheduled maintenance, heat rate, and fixed and variable operating and maintenance (O&M) costs. These components are used to efficiently compute system reliability (such as loss-of-load probability and unserved energy) and production costs.

The input data required by ICARUS include monthly load duration curves, annual peak demands, and, for both new and existing units, unit sizes, capital costs, fixed and variable O&M costs, fuel types and costs, heat rates, scheduled maintenance, and equivalent forced outage rates. The output from ICARUS includes annual summaries of capacity, generation, cost, and reliability for the entire generating system.

CSTM Module

The CSTM module determines the least-cost combination, on a per BTU basis, of coal supply sources and transportation routes for each demand source. First, it estimates coal market prices based on regional demands for coal from all economic sectors. To generate market prices, CSTM estimates regional coal production patterns and coal transportation routes. The CSTM input data are grouped into three major categories: demand, supply, and transportation. CSTM uses supply curves from the Resource Allocation and Mine Costing (RAMC) Model (DOE, 1982). Every region has a separate curve for one or more of the 60 different coal types that may be produced in that region. CSTM modifies the original RAMC supply curve by dividing the single RAMC curve into two curves, one representing deep mines and the other representing surface mines, but still uses the same ranges for heating values and mine prices that define the supply curves in RAMC. Prices fluctuate as a result of different mining methods, size of mining operations, reserve characteristics, and depletion effects.

The transportation data defines the network that connects 32 coal supply origins with 48 demand centers. Transportation cost is affected by distance, terrain, congestion, variable fuel costs, cost escalators for fuels and facility upgrades, and competition. CSTM first computes the production cost for each coal supply region and coal type. It then matches supply sources with transportation routes to find the lowest delivered costs.

Coal demand for a particular region is based on the amount, geographic region, economic sector, and range of coal types. There are 44 domestic demand regions. CSTM allows demand to be met by one, or a combination of, different supply regions.

The ARGUS input data for existing units are based on the Argonne Power Plant Inventory (APPI). APPI is a data base of operating and planned generating units in the United States that was current through 1988 at the time of ANL's analysis. This data base is updated annually based on information in the regional North American Electric Reliability Council (NERC) reports, reports from the Energy Information Administration (EIA), and other sources. Unit operating characteristics (fixed O&M, variable O&M, heat rate, forced outage rate, and scheduled maintenance) are based on regional data as defined in the EPRI report on regional systems and other historic data (EPRI, 1981).

ANL used the 1988 inventory to generate a 1990 inventory. The 1990 inventory was then used to generate a separate unit inventory for the target years 1975, 1980 and 1985. The target year inventories were generated by removing units whose on-line year was greater than the target year, from their respective inventory. The regional capacity totals in these preliminary inventories were tabulated by major fuel category (nuclear, coal, oil and gas steam) and compared to the regional historic NERC totals. This review identified capacity differences, especially in 1975 and 1980 inventories. The original plan was to add phantom units to match the regional historic totals. However, based on the need for State-level emissions, it was decided that a more thorough review of the unit inventories was required.

ANL's detailed review included an examination of the nuclear and coal units greater than 100 megawatt equivalent (MWe) in each target year. Missing units, with the appropriate unit size and State code, were added so that the regional totals were comparable. The availability of coal units was based on the on-line year of the unit as reported in the EIA report *Inventory of Power Plants in the United States* (DOE, 1986). The coal units were also checked against the EIA Cost and Quality Report (EIA, 1985) to verify the existence of flue gas desulfurization (FGD) systems in each of the target years. The nuclear unit inventories were verified with the EIA report *An Analysis of Nuclear Power Plant Operating Costs* (DOE, 1988). The review also included oil and gas steam units greater than 100 MWe. The total capacity of the oil and gas steam units were compared because many units switched primary fuel from oil to gas during the relevant time period. The oil and gas units were compared to historic inventories based on information provided by Applied Economic Research. In addition to thermal generation, the hydro and exchange energy was reviewed. For each target year, the hydro generation and firm purchase and sale capacity data was adjusted to reflect the historic levels. These two components, hydro and firm purchase and sales, are accounted for first in the loading order. If these variables are overestimated, there will be less generation from coal units. Likewise, if they are underestimated, there will be too much coal generation. The hydro and firm purchases and sales can vary significantly from year to year because of weather conditions and other variables. Therefore, it was important that they be accurately represented.

No-control Scenario Emissions

In order to calculate utility emissions under the no-control scenario, inputs to both the CEUM and ARGUS models were adjusted to reflect no-control scenario conditions. The changes made to each model's base year input files are discussed separately in the following sections.

ICF Estimates of SO_2, TSP, and NO_x Emissions in the No-control Scenario

As described earlier, ICF utilized a different methodology to calculate 1975 emission estimates. Rather than relying on the use of detailed modeling runs, ICF based the 1975 emission estimation on historic fuel consumption and sulfur content data in 1975. This subsection first outlines the process used to calculate no-control scenario emissions in 1975 and then presents the methods used for the remaining target years.

1975 Utility SO_2, NO_x, and TSP Emissions

To develop State-level no-control scenario utility SO_2 emissions, ICF developed no-control scenario SO_2 emission rates. A reasonable surrogate for these emission rates is SO_2 rates just prior to the implementation of the SIPs under the CAA. ICF developed 1972 rates (based on the earliest year available for FERC Form 423) and compared these with 1975 rates. In each State, the greater of 1972 or 1975 rates was used in the calculation of SO_2 emissions in the absence of the CAA. To develop State-level no-control scenario SO_2 emissions, no-control scenario fuel consumption data were needed. ICF assumed that the demand for electricity in 1975 would be 2.73 percent higher than the actual energy sales in 1975. This assumption is identical to the no-control scenario electricity demand projections derived from the J/W projections. For the purpose of this analysis, it was further assumed that this increment in demand would have been met in 1975 from the oil and coal-fired plants in each State. The increase in consumption of these fuels was assumed to be in the same proportion as their share in the 1975 total energy mix for electricity generation in that State. It was assumed that the generation of nuclear, gas-fired, and other electricity generation would not change. A sensitivity case without an assumed electricity demand change was also calculated. (The sensitivity analysis results are presented later in this appendix.)

For NO_x emissions under the no-control scenario, it was also assumed that the 1975 electricity sales would have been 2.73 percent higher than was the case in 1975. No-control scenario TSP emissions in 1975 were based on national emission rate numbers from EPA that were converted to pounds per million BTU using the average energy content of fuels in each State. No-control scenario TSP emissions were calculated based on 1970 emission factors (Braine, Kohli, and Kim, 1993).

1980, 1985, and 1990 Utility Emissions

For 1980, 1985, and 1990, ICF calculated no-control scenario emissions based on fuel consumption figures from the CEUM runs, and 1970 emission factors from EPA.

Electric utility SO_2 emission estimates are approximately 10 million tons (or about 38 percent) lower by 1990 under the control scenario than under the no-control scenario. Most of this estimated difference results from the imposition of emission limits at existing power plants through the SIPs under the 1970 CAA. Most of these SIPs were effective by 1980 (with some not fully effective until 1985). Most of the additional reductions that occurred during the 1980s were the result of the electric utility NSPS, which required the installation of 70 to 90 percent SO_2 removal control equipment.

By contrast, electric utility NO_x emission estimates under the control scenario are only about 1.2 million tons, or 14 percent, lower than under the no-control scenario by 1990. This occurs because, under the implementation of the 1970 CAA, only a few existing power plants were subject to NO_x emission limits. Virtually all of the estimated reductions are the result of NO_x NSPS, which generally required moderate reductions at power plants relative to uncontrolled levels. In addition, electricity demand is estimated to be about 3 percent lower under the control scenario. This decrease reduces the utilization of existing power plants and also contributes to lower NO_x emissions (and other pollutants as well).

Electric utility annualized costs (levelized capital, fuel, and O&M) are estimated to be \$0.2 billion lower in 1980, \$1.5 billion higher in 1985, and \$1.9 billion higher in 1990 under the control scenario. Note, however, that this reflects the effects of two offsetting factors: (1) the *higher* utility compliance costs associated with using lower sulfur fuels, and the increased O&M and capital costs associated with scrubbers and particulate control equipment; and (2) *lower* utility generating costs (fuel, operating and capital costs) associated with lower electricity demand requirements. In 1980, the increase in fuel costs due to higher generation requirements (under the no-control scenario), was larger than the decrease in capital and O&M costs and thus yielded a cost increase over the control case.

However, lower electricity demand for the utility sector would translate into higher costs in other sectors (as electricity substitutes are used). This effect was captured to some extent by the original J/W macroeconomic modeling conducted for the present analysis.

Average levelized U.S. electricity rate estimates are approximately 3 percent higher under the control scenario during the 1980s. Note that year by year, electric utility revenue requirements and capital expenditures (not estimated by ICF) would be estimated to have increased by a greater percentage particularly in the 1970s and early 1980s as incremental capital expenditures for scrubbers and ESPs were brought into the rate base.

Significant shifts in regional coal production are estimated to have occurred between the control and no-control scenarios. High sulfur coal producing regions such as Northern Appalachia and the Midwest/ Central West are estimated to have lower production under the control scenario, while lower sulfur coal producing regions such as Central and Southern Appalachia are estimated to have higher coal production.[12]

ARGUS No-control Scenario

Regional fuel prices, for the thermal units, were based on historic information from the EIA Form 423 data for the year 1977, 1980 and 1985. The 1977 data was used for 1975. Fixed and variable O&M costs were adjusted from the 1988 level, and all cost data were converted to 1985 dollars.

The load data were based on regional historic NERC data for each of the target years. The shapes of the monthly load duration curves are the result of modifications based on the data in the EPRI report on regional systems (EPRI, 1981). The shapes were modified to match the projected 1988 monthly load factors for the NERC regions. These load shapes were held constant for all years.

The actual peak-loads were selected from historic information and used with the existing load duration curves. The system was dispatched so that the calculated generation could be compared with historic data. Discrepancies were resolved by adjusting the peak load so that the annual generation was on target. This procedure was repeated for each of the target years.

The electric utilities were expected to have an increase in generation as identified by the J/W data. Table B-11 identifies the increase in national level generation by year. The national level increase in generation was applied to each power pool.

In addition to load changes, coal units with FGD equipment were modified. These units had their FGD equipment removed along with a 3 percent decrease in heat rate, a 2 percentage point decrease in forced outage rate, and a 50 percent decrease in their fixed and variable O&M costs. These changes were incorporated into the ARGUS model for each of the target years. Model runs were then conducted to arrive at estimates of VOC and CO emissions in the no-control scenario.

Table B-11. J/W Estimates of Percentage Increases in National Electricity Generation Under No-control Scenario.

Year	Percentage Increase
1975	2.7%
1980	3.3%
1985	2.8%
1990	3.0%

Estimation of Lead Emissions from Utilities

In order to estimate lead emissions from electric utilities in each of the target years, data from three different sources were used. Energy use data for the control and no-control scenarios were obtained from the national coal use estimates prepared for the section 812 analysis by ICF (Braine and Kim, 1993). The *Trends* data base provided emission factors and control efficiencies, and the Interim 1990 Inventory identified utility characteristics. The ICF data bases provided the amount of coal consumed for both the control and no-control scenarios in each of the target years. A correspondence between the Interim Inventory and the ICF data base was achieved through the plant name variable. Using emission factors for lead and control efficiencies for electric utilities, estimates of lead emissions per plant per year were calculated. These factors were obtained from the *Trends* data base. It was assumed that pollution control on coal-burning power plants under the no-control scenario would be the same as the pollution control level in 1970. Therefore, the control efficiency from 1970 is used as the basis for the no-control case.

[12] At EPA's direction, ICF's analysis did not estimate the effect of shifts in non-utility coal consumption on regional coal production, nor did it consider the possibility that fewer new coal powerplants might have been built due to the CAA as discussed earlier. Both of these factors could result in a greater estimated change in total U.S. coal production than estimated herein although the difference is not likely to be very significant.

CEUM Sensitivity Case

In addition to comparing actual (control scenario) historical costs and emissions with the higher electricity demand under the no-control scenario, ICF also evaluated emissions in a sensitivity case without the CAA (i.e., under the no-control scenario) with the same electricity demand (versus the no-control scenario with higher demand). The purpose of this sensitivity analysis was to isolate the incremental electric utility compliance costs and reductions in emissions associated with the CAA from the lower resulting generation costs and emissions due to lower estimated electricity demand under the CAA. The incremental effects of the CAA when compared with this case indicate:

- Estimated reductions in emissions due to the CAA are somewhat lower if measured against the sensitivity case without the CAA with the same electricity demand than the emissions without the CAA with lower demand. This occurs because lower electricity demand under the no-control scenario sensitivity results in lower utilization of existing coal and oil plants which, in turn, results in lower emissions. As noted above, in some sense, the changes in emissions represent the effects of electric utility compliance actions under the CAA, absent the effect of lower resultant demand for electricity.

- When measured against the sensitivity case without the CAA (with the same electricity demand), electric utility annualized costs are estimated to have increased by about $5 to $6 billion during the 1980 to 1990 period. This reflects the following cost factors: (1) higher annualized capital costs associated primarily with scrubbers and ESPs installed by electric utilities to comply with the CAA; (2) higher O&M costs associated with the additional air pollution control equipment; and (3) higher fuel costs associated with using lower sulfur coal and oil in order to meet the emission limit requirements of the CAA.

Commercial/Residential

The Commercial and Residential Simulation System (CRESS) model was developed by ANL as part of the Emissions and Control Costs Integrated Model Set and used in the NAPAP assessment (*Methods for Modeling Future Emissions and Control Costs, State of Science and Technology, Report 26*) (McDonald and South, 1984). CRESS is designed to project emissions for five pollutants: SO_x, NO_x, VOC, TSP, and CO. The CRESS output is aggregated into residential and commercial subsectors related to both economic activity and fuel use. The introductory material provided in this appendix about CRESS describes the base year as being 1985. It appears in this way because CRESS was originally developed to operate using the 1985 NAPAP Emission Inventory as its base year data set. For the five pollutants reported by CRESS, emission estimates are provided for the following sectors:

- ♦ Commercial/institutional
  - coal, including point and area categories of anthracite and bituminous boilers;
  - liquid fuel, including boiler and space heating uses of residual, distillate, LPG, and other fuels;
  - natural gas boilers, space heaters, and internal combustion engines;
  - wood used in boilers and space heaters; and
  - other mixed or unclassified fuel use.

- ♦ Residential
  - coal, including area sources of anthracite and bituminous;
  - liquid fuel, composed of distillate and residual oil;
  - natural gas; and
  - wood.

- ♦ Miscellaneous
  - waste disposal, incineration, and open burning; and
  - other, including forest fires, managed and agricultural burning, structural fires, cutback asphalt paving, and internal combustion engine testing.

In addition, VOC emissions are projected for these source categories:

- ♦ Service stations and gasoline marketing;

- ♦ Dry-cleaning point and area sources; and

- Other solvents, including architectural surface coating, auto-body refinishing, and consumer/ commercial solvent use.

This section describes the use of CRESS to estimate control and no-control scenario emissions from the commercial/residential sector.

Control Scenario Emissions

For the NAPAP assessment, 1985 CRESS output corresponded to the 1985 NAPAP Inventory (EPA, 1989), which served as the benchmark for any projections. The design of CRESS is such that emissions by NAPAP SCC are input for each State, then projected to future years by scaling them to economic data such as energy demand. In estimating emissions, differences in emission controls associated with new, replacement, and existing equipment are taken into account where such differences are considered significant. The basic modeling approach is shown in the following equation:

$$Q_{t,b} = \left(\frac{Q_0}{E_0}\right), b \times \left(\frac{D_T}{D_0}\right) \times \sum^{j} \left(f_{t,j} \times E_{t,j}\right) \qquad (3)$$

where:

Q = emissions in year t or the base year, year 0

E = emission factor for the source category b in the base year, or for a subcategory j subject to controls in year t (this takes into account changes in emission rates that may occur as a result of emission regulations or technology changes)

D = driver data indicating activity levels in the base and future years

f = fraction of total activity in year t differentially affected by emission controls

The calculations are carried out in two subroutines, one for SO_2, NO_x, TSP and CO, and one for VOC.

Typically SO_2, NO_x, TSP, and CO emissions are projected by multiplying the 1985 NAPAP SCC data or base year data by the ratio of the driver data (activity level) value in the projection year to its value in the base year. Because there are few controls on SO_x or NO_x emissions from the sources covered by CRESS, projected emissions for most sectors are proportional to the expected activity levels. Thus,

$$Q_t = Q_0 \times \left(\frac{D_t}{D_0}\right) \qquad (4)$$

There are a few source types, such as commercial/institutional boilers, for which emission controls are mandated. These are modeled by multiplying the 1985 emission data by the ratio of the controlled emission factor to the base-year emission factor. Emission factors for each source type are weighted by the proportion of base year activity in each subsector to which controls are expected to apply.

$$Q_{t,b} = Q_0 \left[g_{t,b} + \left(\frac{E_{t,n}}{E_{0,b}}\right) \times \left(g_{t,r} + g_{t,n}\right)\right] \qquad (5)$$

where:

g = the fraction of base-year activity accounted for by existing source b, replacement source r, or new source n in year t

The effective emission factor (Et,n) for the sector is calculated by weighing the portions of sectoral emissions subject to NSPS controls and those likely to continue at existing levels. An appropriate Internal Revenue Service-based rate at which new equipment replaces existing sources is applied to each sector in the model. This is done to estimate how emissions might change as older sources are retired and replaced by new sources that emit at lower rates.

The SO_x/NO_x/TSP/CO subroutine varies in new and replacement emission-source fractions subject to NSPS controls. These fractions are applied to the emission-source replacement rates. In addition, ratios for new source emission factors are varied by State. However, emission ratios for any pollutant/source type combination do not vary over the projection period.

The VOC estimation methodology is similar, but allows variation in emission factors over time. Emission ratios are calculated from files of replacement and existing source emission factors weighted by the replacement rate for each sector and new source factors by State. These are input for each 5-year projection interval. For most source categories, VOC controls are not envisioned, and the 1985 NAPAP emissions for the category are simply scaled proportionally to changes in the driver (activity level) data.

For sources to which controls apply, a variation on the following equation is employed:

$$Q_{t,b} = (\frac{Q_0}{E_0}, b) \times (E_{t,b} + g_{t,n} \times E_{t,n})] \qquad (6)$$

In equation 6, the emission factors for new and existing sources are effectively weighted by the proportion of total activity in year t to which controls apply.

In using CRESS for the CAA retrospective analysis, the base year was 1975. CRESS requires emissions information by State and NAPAP source category as input. Since detailed information on emission levels for 1975 by NAPAP source category were not available, the data were developed from a combination of sources. The procedure for calculating 1975 emissions based on the 1985 NAPAP inventory is described below. The emissions module uses these initial values in conjunction with activity estimates to project control and no-control scenario emissions.

Emissions Data

Since the starting point for the analysis was 1975, emissions data by State and SCC for SO_2, NO_x, VOC, TSP, and CO were required. Available emissions information for this year was not at the level of detail needed by CRESS. The 1985 NAPAP Inventory, which contains the necessary level of detail, in conjunction with information from EPA's *National Air Pollutant Emission Estimates, 1940-1990* (*Trends*) and ANL's MSCET, was used to construct an emissions inventory for 1975. The model then uses these emissions as a benchmark for the analysis.

The method for constructing the 1975 emissions data base was consistent for all pollutants; however, two different sources of emissions data were necessary in order to obtain time series information on all pollutants. MSCET contains monthly State-level emission estimates from 1975 to 1985 by emission source group for SO_2, NO_x, and VOC. Therefore, MSCET information was used for SO_2, NO_x, and VOC, while *Trends* data were used for TSP and CO. Emission source groups from MSCET were matched with 1985 NAPAP Inventory SCCs. The MSCET methodology is benchmarked to the 1985 NAPAP Inventory and uses time series information from *Trends* in conjunction with activity information to estimate State-level emissions for SO_2, NO_x, and VOC. Although the level of detail contained in the NAPAP Inventory could not be preserved because of the aggregation needed to match with MSCET emissions sources, MSCET provided the State-level spatial detail required by CRESS.

Once the 1985 emissions by SCC and State from the 1985 NAPAP Inventory were matched with emission source groups and States from the MSCET data base, an estimate of 1975 emissions was computed by multiplying the 1985 NAPAP Inventory emissions value by the ratio of 1975 MSCET emissions to 1985 MSCET emissions. Ratios were computed and applied for each combination of State, pollutant, and MSCET emission source group.

This method of constructing an emissions inventory for 1975 utilizes the State estimates from MSCET, thus capturing the spatial shifts that occurred over the analysis period. It is assumed that NAPAP provides the most reliable point and area source information in terms of the level of 1985 emissions (which is also the assumption of the MSCET methodology). Note that if there were a 1-to-1 correspondence between MSCET and NAPAP, this method would be equivalent to using the MSCET methodology directly for constructing 1975 emission levels.

A similar method was used for TSP and CO, but since these pollutants are not included in MSCET, the *Trends* ratio of 1975 to 1985 emissions for these two pollutants was used. Thus, for TSP and CO, all States were assumed to have experienced the same change in emissions as indicated by the national figures.

It should be noted that in addition to the loss in spatial detail, the *Trends* source groups generally spanned several NAPAP source categories. The strength in the *Trends* information is the consistency of emissions estimates over time. It is considered to be the most reliable data for tracking changes in emissions over the time period of the analysis, and was therefore chosen for developing 1975 estimates for TSP and CO.

The 15 source categories reported in *Trends* were matched with those in the 1985 NAPAP Inventory. The ratios of 1975 emissions to 1985 emissions by source category that were applied to the 1985 NAPAP emissions data are shown in B-12. The 1975 emis-

Table B-12. *Trends* Source Categories and (1975 to 1985) Scaling Factors for TSP and CO.

***Trends* Source Category**	**TSP***	**CO***
Commercial/Institutional Fuel Combustion:		
Coal	2.11	0.59
Natural Gas	1.00	0.91
Fuel Oil	2.35	1.43
Other	1.83	0.67
Residential Fuel Combustion:		
Coal	1.33	1.47
Natural Gas	1.17	1.00
Fuel Oil	1.11	1.76
Wood	0.49	0.49
Miscellaneous: Forest Fires	0.67	0.62
Solid Waste Disposal:		
Incineration	3.00	0.64
Open Burning	1.50	1.44
Miscellaneous Other Burning	1.00	1.33
Industrial Processes: Paving	2.71	0.56
Asphalt Paving and Roofing	2.71	0.56
Miscellaneous Other	1.83	0.67

Note: *These values are the ratios of 1985 *Trends* emissions to 1975 *Trends* emissions for each source category. For example, the commercial/ institutional fuel combustion: coal emission ratio of 2.11 is computed as the ratio of the 1975 TSP emissions of 40 gigagrams per year to the corresponding 1985 emissions of 19 gigagrams per year.

sions data estimated from the above procedure served as the benchmark and initial value for the CRESS emissions module for both scenarios.

CAA regulation of commercial/ residential emissions was limited and largely confined to fuel combustion sources (SO_2, NO_x, TSP), gasoline marketing (VOC), dry cleaning (VOC), and surface coating (VOC). NSPS regulations of small (over 29 MW capacity) fuel combustors were promulgated in 1984 and 1986. For purposes of emissions calculations, the stipulated NSPS for SO_2, NO_x, and TSP were incorporated into the control scenario for 1985 and 1990. Emission rates for source categories subject to VOC regulation were similarly adjusted.

Energy Data

Nearly 75 percent of the source categories in CRESS use energy consumption by State and sector as the driver for the emissions calculation. State-level energy consumption statistics are published by EIA in *State Energy Data Report, Consumption Estimates, 1960-1989,* and are electronically available as part of the State Energy Data System (SEDS) (DOE, 1991). The SEDS data base contains annual energy consumption estimates by sector for the various end-use sectors: residential, commercial, industrial and transportation, and electric utilities.

Seven fuel-type categories are used in CRESS: coal, distillate oil, residual oil, natural gas, liquid petroleum gas, wood, and electricity. The model assumes zero consumption of residual fuel oil in the residential sector and zero consumption of wood in the commercial sector. Energy consumption for each fuel-type was expressed in BTUs for purposes of model calculations. With the exception of wood consumption, all of the energy consumption statistics used in CRESS were obtained from SEDS.

Residential wood consumption estimates were derived from two data sources. State-level residential sector wood consumption estimates for 1975 and 1980 were obtained from *Estimates of U.S. Wood Energy Consumption from 1949 to 1981* (EIA, 1982). State-level wood consumption, however, was not available for 1985 and 1990, therefore, regional information from an alternative publication, *Estimates of U.S. Biofuels Consumption 1990* (EIA, 1990), was used to derive State-level residential wood use figures. Regional 1985 and 1990 wood consumption was distributed among States using 1981 State shares. All wood consumption figures were converted to BTU's using an average value of 17.2 million BTU per short ton.

Economic/Demographic Data

Emissions from slightly more than 25 percent of the CRESS source categories follow State-level economic and demographic activity variables. The demographic variables used by CRESS include State-level population, rural population, and forest acreage. State population is the activity indicator for six emissions source categories for SO_2, NO_x, TSP, and CO, and 13 VOC source categories. State population data were assembled from the SEDS data base. Rural population, which is the indicator of residential open burning activity, is computed as a fraction of total State population. Forest wildfires and managed open burning activity are related to 1977 State-level forest acreage. The demographic information is assumed to be invariant to CAA regulations and thus is the same in the control and no-control scenarios.

Car stock (or vehicle population), the driver variable for the auto body refinishing, is approximated by State motor vehicle registrations. *Highway Statistics*, an annual publication by the FHWA, was the source for data on State motor vehicle registrations. The three source categories connected with gasoline marketing are driven by State-level gasoline sales in gallons. State gasoline consumption was obtained from the SEDS data base. Housing starts and 10 percent of the existing housing stock were combined to form the activity indicator for architectural surface coating emissions. Housing data compiled by the U.S. Bureau of the Census were available in the *Statistical Abstract of the United States* (DOC, 1975; 1977; 1982; 1983; 1987; 1993). Regional-level data for 1975 was allocated to the States based on the 1980 State distribution.

No-control Scenario Emissions

Adjustments to control scenario emissions in each of the target years to reflect conditions under the no-control scenario were achieved through emission factors, energy input data, and economic/demographic data. The adjustments made to each of these variables to generate no-control scenario emissions are discussed individually in the following subsections.

Emissions Data

CAA regulation of the commercial/residential sector was minimal. For regulated source categories, emission factors were revised to reflect pre-regulation emission rates. Six commercial/residential source categories were regulated for VOC emissions: Service Stations Stage I Emissions, Service Stations Stage II Emissions, Dry Cleaning (perchloroethylene), Gasoline Marketed, Dry Cleaning (solvent), and Cutback Asphalt Paving. Commercial-Institutional boilers were regulated for SO_2 and TSP and internal combustion sources were regulated for NO_x emissions. All NSPS were removed for these sources to estimate no-control scenario emissions levels.

Energy Data

State-level energy demand for the residential and commercial sectors for the no-control scenario was estimated from the J/W model forecast. Final energy demand estimates for the household sector were calculated by an EPA contractor for the purposes of the no-control scenario analysis. State allocation of the national-level estimates was based on historic State shares, i.e., this assumes that there is no change in the distribution of energy demand across States as a result of removing regulations. In addition, the J/W model estimates an aggregate refined petroleum category and does not distinguish among liquid petroleum gas, distillate oil, and residual oil. The relative shares among these three categories of petroleum products remained constant between the control and no-control scenarios. The information on percentage change in energy demand by fuel type as provided by the J/W model is listed in Table B-13.

The differential for commercial sector final energy demand was calculated from the combination of four intermediate product flow categories from the J/W forecast. The National Income and Product Accounts (NIPA) for the commercial sector correspond to J/W SIC categories 32 through 35:

Table B-13. Percentage Change in Real Energy Demand by Households from Control to No-control Scenario.

Year	Coal	Refined Petroleum	Electric	Natural Gas
1975	1.48	4.76	3.62	2.42
1980	1.50	3.84	4.26	2.12
1985	1.98	3.90	3.88	2.41
1990	2.23	4.33	4.18	2.77

(32) Wholesale and Retail Trade;
(33) Finance, Insurance, and Real Estate;
(34) Other Services; and
(35) Government Services.

Percentage change information from the J/W forecast for energy cost shares, value of output, and energy prices was used to calculate the differential in commercial sector energy demand for the no-control scenario. The energy cost share is defined as the cost of energy input divided by the value of the output. In order to calculate the percentage change in commercial sector energy demand, the change in energy price was subtracted from the percentage change in energy cost, and added to the change in the value of output. Each of these variables was available from the J/W model results. This calculation was performed for each of the four energy types, and each of the four NIPA categories. The change in commercial sector energy demand was obtained by taking the weighted average of the four NIPA categories. Since data on relative energy demand for NIPA categories were not readily available, square footage was used as a proxy for calculating the weights. These data were taken from the *Nonresidential Buildings Energy Consumption Survey, Commercial Buildings Consumption and Expenditure 1986* (EIA, 1989). The resulting estimate for commercial sector changes in energy demand is provided in Table B-14.

Table B-14. Percentage Change in Commercial Energy Demand from Control to No-control Scenario.

Year	Coal	Refined Petroleum	Electric	Natural Gas
1975	-0.13	3.36	1.30	-0.80
1980	0.31	1.90	2.06	-0.82
1985	0.48	1.98	1.72	-0.40
1990	0.39	2.26	1.74	-0.22

The national-level change in commercial sector energy demand was allocated to the States using historic shares. Implicit is the assumption that removal of CAA regulations does not alter the State distribution of energy use.

Economic/Demographic Data

State population was assumed not to vary as a result of CAA regulations, thus only the economic variables were revised for the no-control scenario. No-control scenario housing starts and car stock were derived from J/W forecast information on construction and motor vehicles. The differential for categories 6 (construction) and 24 (motor vehicles and equipment) was applied to control scenario values to obtain no-control scenario levels. The percentage change from the J/W forecast is given in Table B-15.

State-level gasoline sales is one of the activities forecasted by the transportation sector model. The percentage change in gasoline sales calculated by the TEEMS model was used in the no-control scenario as a CRESS model input.

Table B-15. J/W Percent Differential in Economic Variables Used in CRESS.

Year	Construction	Motor Vehicles
1975	0.70	5.04
1980	0.14	4.79
1985	0.41	6.07
1990	0.29	6.25

Table B-16. TSP Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

	With the CAA				Without the CAA				Difference in 1990
Sector	**1975**	**1980**	**1985**	**1990**	**1975**	**1980**	**1985**	**1990**	**Emissions**
Transportation:									
Highway Vehicles	700	760	770	820	770	910	1,030	1,180	(30%)
Off-Highway Vehicles	270	280	270	280	260	270	260	270	5%
Stationary Sources:									
Electric Utilities	1,720	880	450	430	3,460	4,480	5,180	5,860	(93%)
Industrial Processes	5,620	3,650	3,040	3,080	11,120	12,000	11,710	12,960	(76%)
Industrial Boilers	740	480	250	240	780	550	360	400	(41%)
Commercial/Residential	2,020	2,510	2,680	2,550	2,020	2,520	2,700	2,560	(1%)
TOTAL*	11,070	8,550	7,460	7,390	18,410	20,730	21,250	23,230	(68%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Table B-17. SO_2 Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

	With the CAA				Without the CAA				Difference in 1990
Sector	**1975**	**1980**	**1985**	**1990**	**1975**	**1980**	**1985**	**1990**	**Emissions**
Transportation:									
Highway Vehicles	380	450	500	570	380	450	500	560	1%
Off-Highway Vehicles	370	530	410	390	360	530	400	390	1%
Stationary Sources:									
Electric Utilities	18,670	17,480	16,050	16,510	20,690	25,620	25,140	26,730	(38%)
Industrial Processes	4,530	3,420	2,730	2,460	5,560	5,940	5,630	6,130	(60%)
Industrial Boilers	3,440	3,180	2,660	2,820	3,910	4,110	4,020	4,610	(39%)
Commercial/Residential	1,000	800	590	690	1,000	810	610	710	(3%)
TOTAL*	28,380	25,860	22,950	23,440	31,900	37,460	36,310	39,140	(40%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Table B-18. NO_x Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

	With the CAA				Without the CAA				Difference in 1990
Sector	**1975**	**1980**	**1985**	**1990**	**1975**	**1980**	**1985**	**1990**	**Emissions**
Transportation:									
Highway Vehicles	8,640	9,340	8,610	8,140	9,020	11,060	13,160	15,390	(47%)
Off-Highway Vehicles	1,990	2,180	2,080	2,090	1,980	2,150	2,040	2,060	1%
Stationary Sources:									
Electric Utilities	5,540	6,450	6,660	7,060	5,740	7,150	7,780	8,300	(15%)
Industrial Processes	750	760	690	710	760	830	790	1,090	(35%)
Industrial Boilers	4,090	3,680	3,540	3,710	4,120	3,660	3,680	3,900	(5%)
Commercial/Residential	1,060	960	880	930	1,060	970	890	950	(2%)
TOTAL*	22,060	23,370	22,460	22,640	22,680	25,830	28,350	31,680	(29%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Table B-19. VOC Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

	With the CAA				Without the CAA				Difference in 1990
Sector	**1975**	**1980**	**1985**	**1990**	**1975**	**1980**	**1985**	**1990**	**Emissions**
Transportation:									
Highway Vehicles	12,220	10,770	9,470	7,740	14,620	16,460	19,800	23,010	(66%)
Off-Highway Vehicles	1,380	1,370	1,340	1,410	1,390	1,420	1,390	1,490	(5%)
Stationary Sources:									
Electric Utilities	20	30	30	40	20	30	30	40	(7%)
Industrial Processes	5,910	6,780	6,230	5,630	6,130	7,930	7,290	6,810	(17%)
Industrial Boilers	150	150	150	150	150	150	140	150	0%
Commercial/Residential	4,980	5,480	5,820	5,870	4,980	5,700	6,080	6,130	(4%)
TOTAL*	24,660	24,580	23,030	20,840	27,290	31,680	34,730	37,630	(45%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Table B-20. CO Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

Sector	With the CAA 1975	With the CAA 1980	With the CAA 1985	With the CAA 1990	Without the CAA 1975	Without the CAA 1980	Without the CAA 1985	Without the CAA 1990	Difference in 1990 Emissions
Transportation:									
Highway Vehicles	83,580	79,970	72,490	65,430	90,460	105,530	131,420	149,280	(56%)
Off-Highway Vehicles	8,510	8,100	7,880	8,080	8,510	8,070	7,880	8,080	0%
Stationary Sources:									
Electric Utilities	240	280	290	370	250	290	300	380	(3%)
Industrial Processes	7,580	6,990	4,840	5,140	9,240	9,120	8,860	10,180	(49%)
Industrial Boilers	720	710	670	740	720	710	620	740	0%
Commercial/Residential	10,250	13,130	14,140	13,150	10,250	13,170	14,200	13,210	0%
TOTAL*	110,880	109,170	100,300	92,900	119,430	136,880	163,280	181,860	(49%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Table B-21. Lead (Pb) Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

Sector	With the CAA 1975	With the CAA 1980	With the CAA 1985	With the CAA 1990	Without the CAA 1975	Without the CAA 1980	Without the CAA 1985	Without the CAA 1990	Difference in 1990 Emissions
Transportation:									
Highway Vehicles	180	86	22	2	203	207	214	223	(99%)
Stationary Source:									
Industrial Processes	3	1	1	1	7	7	6	5	(87%)
Industrial Combustion	4	2	0	0	5	5	5	5	(96%)
Utilities	1	1	0	0	2	3	4	4	(95%)
TOTAL*	190	90	23	3	217	221	228	237	(99%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Emissions Modeling References

Abt Associates Inc. (Abt). 1995. *The Impact of the Clean Air Act on Lead Pollution: Emissions Reductions, Health Effects, and Economic Benefits from 1970 to 1990*, Final Report, Bethesda, MD, October.

Argonne National Laboratory (ANL). 1990. *Current Emission Trends for Nitrogen Oxides, Sulfur Dioxide, and Volatile Organic Chemicals by Month and State: Methodology and Results*, Argonne, IL, August.

Argonne National Laboratory (ANL). 1992. *Retrospective Clean Air Act Analysis: Sectoral Impact on Emissions from 1975 to 1990*, (Draft), Argonne, IL, July.

Braine, Bruce and P. Kim. 1993. *Fuel Consumption and Emission Estimates by State*, ICF Resources, Inc., Fairfax, VA, memorandum to Jim DeMocker, EPA. April 21.

Braine, Bruce, S. Kohli, and P. Kim. 1993. *1975 Emission Estimates with and without the Clean Air Act*, ICF Resources, Inc., Fairfax, VA, memorandum to Jim DeMocker, EPA, April 15.

DeMocker, J. Personal Communication with Office of Mobile Sources Staff, Ann Arbor, Michigan. Date unknown.

Energy Information Administration (EIA). 1982. *Estimates of U.S. Wood Energy Consumption from 1949 to 1981*. DOE/EIA-0341, U.S. Department of Energy. August.

Energy Information Administration (EIA). 1985. *Cost and Quality of Fuels for Electric Utility Plants*. DOE/EIA-0091(85), U.S. Department of Energy.

Energy Information Administration (EIA). 1989. *Nonresidential Buildings Energy Consumption Survey: Commercial Buildings Consumption and Expenditures 1986*. DOE/EIA-0318(86), U.S. Department of Energy. May.

Energy Information Administration (EIA). 1990. *Estimates of U.S. Biofuels Consumption 1990*. DOE/EIA-0548(90), U.S. Department of Energy. October.

Electric Power Research Institute (EPRI). 1981. *The EPRI Regional Systems*, EPRI-P-1950-SR, Palo Alto, CA.

Federal Highway Administration (FHWA). 1986. *1983-1984 Nationwide Personal Transportation Survey*, U.S. Department of Transportation, Washington, DC.

Federal Highway Administration (FHWA). 1988. *Highway Statistics 1987*, PB89-127369, U.S. Department of Transportation, Washington, DC.

Federal Highway Administration (FHWA). 1992. *Highway Statistics 1991*, FHWA-PL-92-025, U.S. Department of Transportation, Washington, DC.

Gschwandtner, Gerhard. 1989. *Procedures Document for the Development of National Air Pollutant Emissions Trends Report*, E.H. Pechan & Associates, Inc., Durham, NC. December.

Hogan, Tim. 1988. *Industrial Combustion Emissions Model (Version 6.0) Users Manual*, U.S. Environmental Protection Agency, EPA-600/8-88-007a.

ICF Resources, Inc. 1992. *Results of Retrospective Electric Utility Clean Air Act Analysis - 1980, 1985 and 1990*, September 30.

Jorgenson, D.W. and P. Wilcoxen. 1989. *Environmental Regulation and U.S. Economic Growth*, Harvard University Press, Cambridge, MA.

Klinger, D. and J.R. Kuzmyak. 1986. *Personal Travel in the United States, Vol. I: 1983-84 Nationwide Personal Transportation Study*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC. August.

Kohout, Ed. 1990. *Current Emission Trends for Nitrogen Oxides, Sulfur Dioxide, and Volatile Organic Compounds by Month and State: Methodology and Results,*" Argonne National Laboratory, ANL/EAIS/TM-25, Argonne, IL.

Lockhart, Jim. 1992. *Projecting with and without Clean Air Act Emissions for the Section 812 Retrospective Analysis: A Methodology Based Upon the Projection System used in the Office of Air Quality Planning and Standards National Air Pollutant Emission Estimate Reports*," (Draft Report), Environmental Law Institute, November 16.

McDonald, J.F. and D.W. South. 1984. *The Commercial and Residential Energy Use and Emissions Simulation System (CRESS): Selection Process, Structure, and Capabilities*, Argonne National Laboratory, ANL/EAIS/TM-12, Argonne, IL. October.

Mintz, M.M. and A.D. Vyas. 1991. *Forecast of Transportation Energy Demand through the Year 2010*, Argonne National Laboratory, ANL/ESD-9, Argonne, IL. April.

Pechan Associates. 1995. *The Impact of the Clean Air Act on 1970 to 1990 Emissions; Section 812 Retrospective Analysis*. Draft Report. March.

Saricks, C.L. 1985. *The Transportation Energy and Emissions Modeling System (TEEMS): Selection Process, Structure, and Capabilities*, Argonne National Laboratory, ANL/EES-TM-295, Argonne, IL. November.

Veselka, T.D., et al. 1990. *Introduction to the Argonne Utility Simulation (ARGUS) Model*," Argonne National Laboratory, ANL/EAIS/TM-10, Argonne, IL. March.

Vyas, A.D. and C.L. Saricks. 1986. *Implementation of the Transportation Energy and Emissions Modeling System (TEEMS) in Forecasting Transportation Source Emissions for the 1986 Assessment*, Argonne National Laboratory, ANL/EES-TM-321, Argonne, IL. October.

U.S. Department of Commerce (DOC). 1975. *Statistical Abstract of the United States: 1975 (96th Edition)*, Bureau of the Census, Washington, DC, September.

U.S. Department of Commerce (DOC). 1977. *Statistical Abstract of the United States: 1977 (98th Edition)*, Bureau of the Census, Washington, DC, September.

U.S. Department of Commerce (DOC). 1981. *1977 Truck Inventory and Use Survey*, Bureau of the Census, TC-77-T-52, Washington, DC, August.

U.S. Department of Commerce (DOC). 1982. *Statistical Abstract of the United States: 1982-1983 (103rd Edition)*, Bureau of the Census, Washington, DC, December.

U.S. Department of Commerce (DOC). 1983. *Statistical Abstract of the United States: 1984 (104th Edition)*, Bureau of the Census, Washington, DC, December.

U.S. Department of Commerce (DOC). 1984. *1982 Truck Inventory and Use Survey*, Bureau of the Census, TC-82-T-52, Washington, DC, August.

U.S. Department of Commerce (DOC). 1987. *Statistical Abstract of the United States: 1988 (108th Edition)*, Burea of the Census, Washington, DC, December.

U.S. Department of Commerce (DOC). 1990. *1987 Truck Inventory and Use Survey*," Bureau of the Census, TC87-T-52, Washington, DC, August.

U.S. Department of Commerce (DOC). 1991. *Annual Survey of Manufactures: Purchased Fuels and Electric Energy Used for Heat and Power by Industry Group*, Bureau of the Census, M87(AS)-1, Washington, DC.

U.S. Department of Commerce (DOC). 1993. *Statistical Abstract of the United States: 1993 (113th Edition)*," Bureau of the Census, Washington, DC.

U.S. Department of Energy (DOE). 1982. *Documentation of the Resource Allocation and Mine Costing (RAMC) Model*. DOE/NBB-0200. Energy Information Administration.

U.S. Department of Energy (DOE). 1986. *Inventory of Power Plants in the United States 1985*. DOE/EIA-0095(85), Energy Information Administration, Washington, DC, August.

U.S. Department of Energy (DOE). 1988. *An Analysis of Nuclear Power Plant Operating Costs*. DOE/EIA-0511(88), Energy Information Administration.

U.S. Department of Energy (DOE). 1990. *State Energy Price and Expenditure Report 1988*. DOE/EIA-0376(88), Energy Information Administration, Washington, DC, September.

U.S. Department of Energy (DOE). 1991. *State Energy Data Report: Consumption Estimates - 1960-1989*. DOE/EIA-0214(89), Energy Information Administration, Washington, DC, May.

U.S. Department of Energy (DOE). 1992. *Annual Energy Review 1991*. DOE/EIA-0384(91), Energy Information Administration, Washington, DC.

U.S. Environmental Protection Agency (EPA). 1985. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources*, AP-42, Fourth Edition, GPO No. 055-000-00251-7, Research Triangle Park, NC. September.

U.S. Environmental Protection Agency (EPA). 1989. *The 1985 NAPAP Emissions Inventory*, EPA-600/7-89-012a, Research Triangle Park, NC. November.

U.S. Environmental Protection Agency (EPA). 1990. *The Cost of a Clean Environment*, EPA-230-11-90-083. November.

U.S. Environmental Protection Agency (EPA). 1991. Office of Air Quality Planning and Standards, *National Air Pollutant Emissions Estimates, 1940-1990*, EPA-450/4-91-026, Research Triangle Park, NC. November.

U.S. Environmental Protection Agency (EPA). 1992. *1990 Toxics Release Inventory*, EPA-700-S-92-002, Washington, DC.

U.S. Environmental Protection Agency (EPA). 1994a. *National Air Pollutant Emission Trends, 1900-1993*, EPA-454/R-94-027, Office of Air Quality Planning and Standards, Research Triangle Park, NC. October.

U.S. Environmental Protection Agency (EPA). 1994b. Office of Mobile Sources, *User's Guide to MOBILE5 (Mobile Source Emission Factor Model)*, EPA-AA-AQAB-94-01, Ann Arbor, MI. May.

U.S. Environmental Protection Agency (EPA). 1995. *National Air Pollutant Emission Trends 1900-1994*, EPA-454/R-95-011. Office of Air Quality Planning and Standards, Research Triangle Park, NC. October.

Werbos, Paul J. 1983. *A Statistical Analysis of What Drives Energy Demand: Volume III of the PURHAPS Model Documentation*, U.S. Department of Energy, Energy Information Administration, DOE/EIA-0420/3, Washington, DC.